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Regional and Local Patterns of CO_2-K-Rb-As Alteration: A Guide to Gold in the Timmins Area

by

J.F. Davies, R.E.S. Whitehead, R.A. Cameron and D.Duff

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TABLE OF CONTENTS

List of Tables	ii
List of Figures	iii
Abstract	1
Introduction	2
Carbonate Species, CO_2/CaO Molar Ratios	4
Regional Carbonate, Alkali and As Levels	8
Target Anomalies	9
Localization of Alteration and Gold Mineralization	19
Application to Gold Exploration	22
Acknowledgements	24
References	25
Appendix A Analytical Data for Certain Major & Trace Components	27

List of Tables

		Page
Table 1.	Means and Standard Deviation, Unmineralized Control Areas and Mineralized, Timmins Area	10
Table 2.	K_2O, Rb, As Contents Related to Intensity of Alteration in the Sub-groups of the Tisdale Group	12
Table 3.	Classification of 111 "Mineralized" Samples Directly Associated with Gold-bearing Veins at Dome and Pamour #1 Mines	14
Table 4.	CO_2/CaO, K_2O, As Levels Relative to Gold Mineralization, Surface Samples, Timmins	16
Table 5	Combinations of CO_2/CaO, K_2O, As (Category and Sub-category) Relative to Gold Mineralization, Surface Samples, Timmins District	17

Ontario Geoscience Research Grant #30

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FINAL REPORT

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List of Figures

Figure 1. Geology and Structure of the Timmins District. (NTA North Tisdale Syncline; CTA Central Tisdale Anticline; PS Porcupine Syncline; VA Vipond Anticline; KS Kayorum Syncline; GLF Gillies Lake Fault; HF Hollinger Fault; DF Dome Fault; DPF Destor-Porcupine Fault; BBF Burrows-Benedict Fault).

Figure 2. Sample locations and Gold Mines.

Figure 3. Binary immobile element (TiO_2-Y) plot of volcanic rocks from the 4 sub-groups of the Tisdale Group.

Figure 4. Plot of % CO_2 against CO_2/CaO Molar Ratio, sample $^{S}_{A}$ of altered basalt, Timmins area. See text for significance of symbols.

Figure 5. Contours of % CO_2, Timmins District.

Figure 6. Contours of CO_2/CaO Molar Ratios, Timmins District.

Figure 7. Contours of ppm As, Timmins District.

Figure 8. Contours of % K_2O, Timmins District.

Figure 9. Contours of ppm Rb, Timmins District.

Figure 10. Contours of % Na_2O, Timmins District.

Figure 11. Frequency Distribution Plots of CO_2/CaO, As, K_2O and Rb from the mineralized Timmins District and Unmineralized Control Areas. The CO_2/CaO ratios are arithmetic; K_2O, As and Rb are logarithmic.

Figure 12. Local CO_2/CaO, As, K_2O and Rb Anomalies, Timmins District.

Figure 13. Profile of CO_2/CaO, As, and K_2O, Dome and Pamour Mines. Q refers to quartz veins; A refers to "ankerite" veins, Dome Mine only.

Figure 14. Plot of As against CO_2/CaO, Pamour #1 and Dome Mines. All samples are associated with gold mineralization.

Figure 15. Plot of K_2O against CO_2/CaO, Pamour #1 and Dome Mines. All samples are associated with gold mineralization.

Figure 16. Plot of As against CO_2/CaO, surface samples, Timmins District. Samples associated with know gold mineralization are shown by solid black circles.

Figure 17. Plot of K_2O against CO_2/CaO, surface samples, Timmins District. Samples associated with known gold mineralization are shown by solid black circles.

Figure 18. Sample sites (upper ~~half~~ left) and plots of CO_2/CaO, K_2O and As, relative to veins on part of the 1400-foot level, Pamour #1 Mine.

Abstract

Although CO_2 content indicates the quantity of carbonate in altered basaltic rocks, it does not measure the intensity of carbonate alteration. CO_2/CaO molar ratios, which correlate with the relative proportions of individual carbonate species, measure the intensity of carbonatization. The Timmins gold area is characterized by pervasive carbonatization, with large parts of the area having CO_2/CaO greater than 1, representing CO_2 supersaturation relative to CaO. The mean CO_2/CaO in the Timmins area is 0.67 compared to 0.13 in two unmineralized control areas. Regional arsenic abundance in the gold-bearing area averages 4 ppm compared to about 0.35 ppm for the non-mineralized areas. The average K_2O and Rb abundances are similar in both mineralized and non-mineralized areas (about 0.30% K_2O and 7 ppm Rb). Although there appears to have been no wholesale addition of K_2O or Rb to the mineralized area from external sources these alkalies have been redistributed internally, resulting in patterns of local enrichments and depletions which are characteristic of the mineralized region.

Local target anomalies associated with known mineralization consist of $CO_2/CaO > 1.5$, As > 10 ppm and $K_2O > 0.75\%$. Not all three values are required to be above these thresholds in order to identify local targets. Combinations such as $CO_2/CaO > 1.5$ and As < 10 ppm, CO_2/CaO 1-1.5 and $K_2O > 0.75$ or $K_2O > 0.75$ and As > 10 ppm are equally indicative of proximity to gold occurrences. Gold-bearing veins and associated anomalies occur

throughout the entire volcanic succession and are not restricted to any particular stratigraphic horizons. The levels and patterns of alteration and the occurrences of gold appear to be structurally controlled.

Introduction

Although carbonatization, alkali alteration and arsenic enrichment are characteristic of wall-rocks surrounding many gold-bearing quartz veins in mafic volcanic rocks (Boyle, 1979), few data are available on the distribution, intensity or patterns of alteration beyond the wall-rocks immediately adjacent to the veins. The purpose of this study is:

1) to compare regional abundances of CO_2, alkalies and As in a mineralized area with those in lithologically comparable but unmineralized areas;
2) to determine local variations in intensity and extent of alteration and their relationship to gold-bearing areas;
3) to define regional and local target anomalies that might be useful in gold exploration.

CO_2, CaO, K_2O, Na_2O, Rb and As were determined for approximately 400 surface samples and 120 mine samples from the test area, Tisdale township and parts of the adjacent townships. Similar determinations were made for about 100 samples from unmineralized control areas in Zavitz, Semple, Hutt and Douglas townships south of Timmins, and in Holloway, Thackery and Elliot townships east of Timmins. Immobile trace

element contents (TiO_2, Y, Zr) were used to establish that the samples from the mineralized area were originally chemically equivalent, within limits, to those from the unminerlaized control areas.

This study was essentially regional, with detail only down to target dimensions, i.e. to within 150 meters of known gold occurrences. No attempt has been made to correlate anomalies with the gold content of the wall-rocks immediately adjacent to veins. Detectable gold anomalies, in the ppb range, rarely extend more than a few tens of meters from veins and are, therefore, much smaller than the large carbonate, alkali and As anomalies outlining general targets. Gold analysis would be useful in identifying individual drill targets within the target area encompassed by the carbonate, alkali and As anomalies.

Figure 1 outlines the geology and structure of the test area; sample sites and the locations of both past and present gold producers are on Figure 2. The Sub-groups of the Tisdale Group are those established for the mines of the area (Ferguson, 1967). The surface distribution and configuration of the 4 Sub-groups displayed in Figure 1 have been confirmed from TiO_2, Cr, Zr and Y plots (Davies, Grant and Whitehead, 1979; Davies and Whitehead, 1980). Figure 3 is a typical binary immobile element plot illustrating the characteristic Ti-Y fields for each of the 4 Sub-groups.

The structure of the area (Figure 1) is essentially that presented by Davies (1977) and is consistent with the volcanic stratigraphy which in turn is supported by the immobile trace element data. Arguments for the existence of the Dome Fault (DF), disputed by Roberts (1980), the

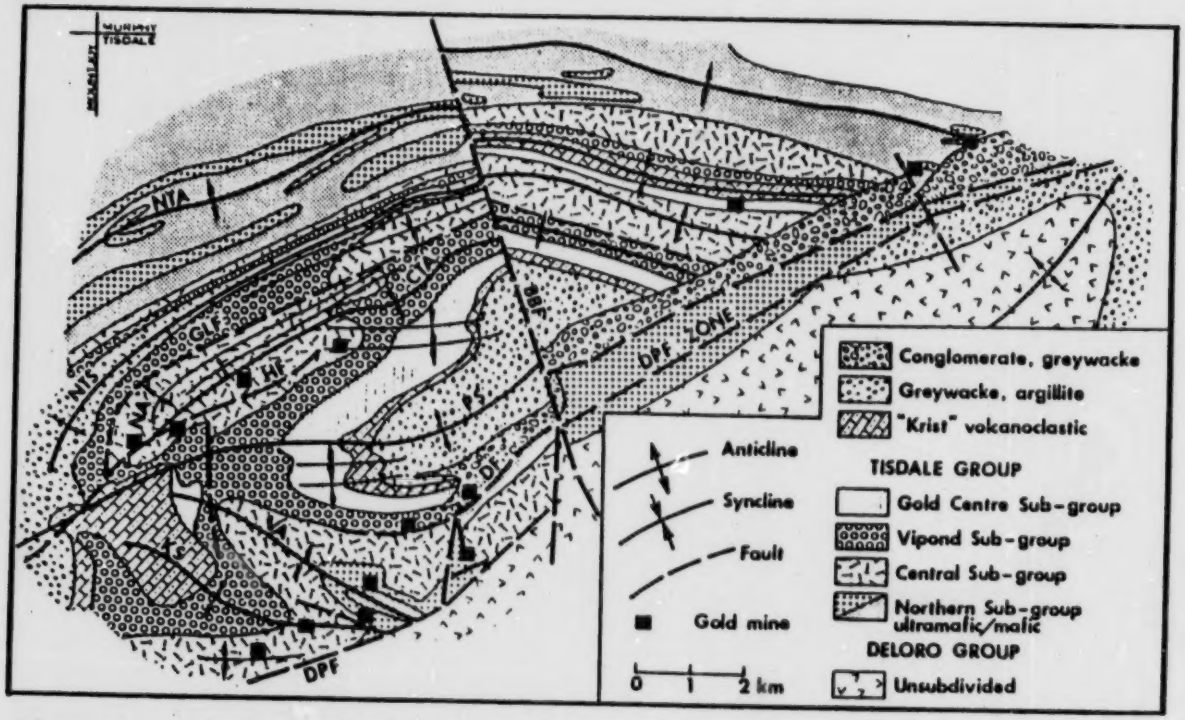

Figure 1. Geology and Structure of the Timmins District. (NTA North Tisdale Syncline; CTA Central Tisdale Anticline; PS Porcupine Syncline; VA Vipond Anticline; KS Kayorum Syncline; GLF Gillies Lake Fault; HF Hollinger Fault; DF Dome Fault; DPF Destor-Porcupine Fault; BBF Burrows-Benedict Fault).

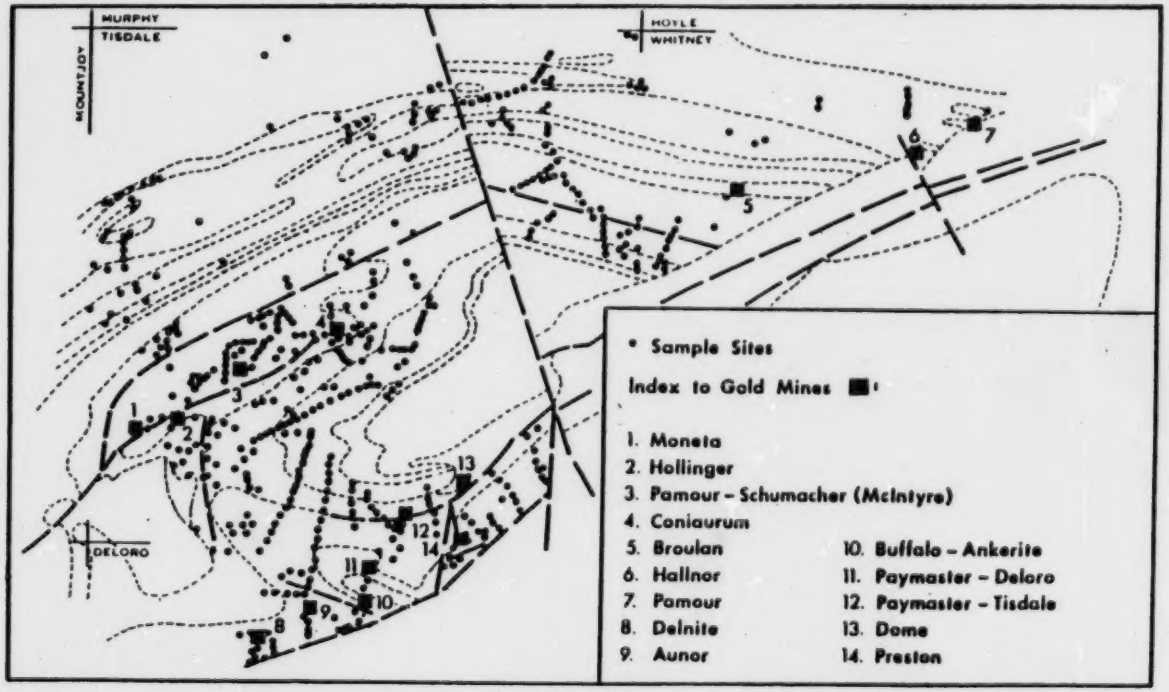

Figure 2. Sample locations and Gold Mines.

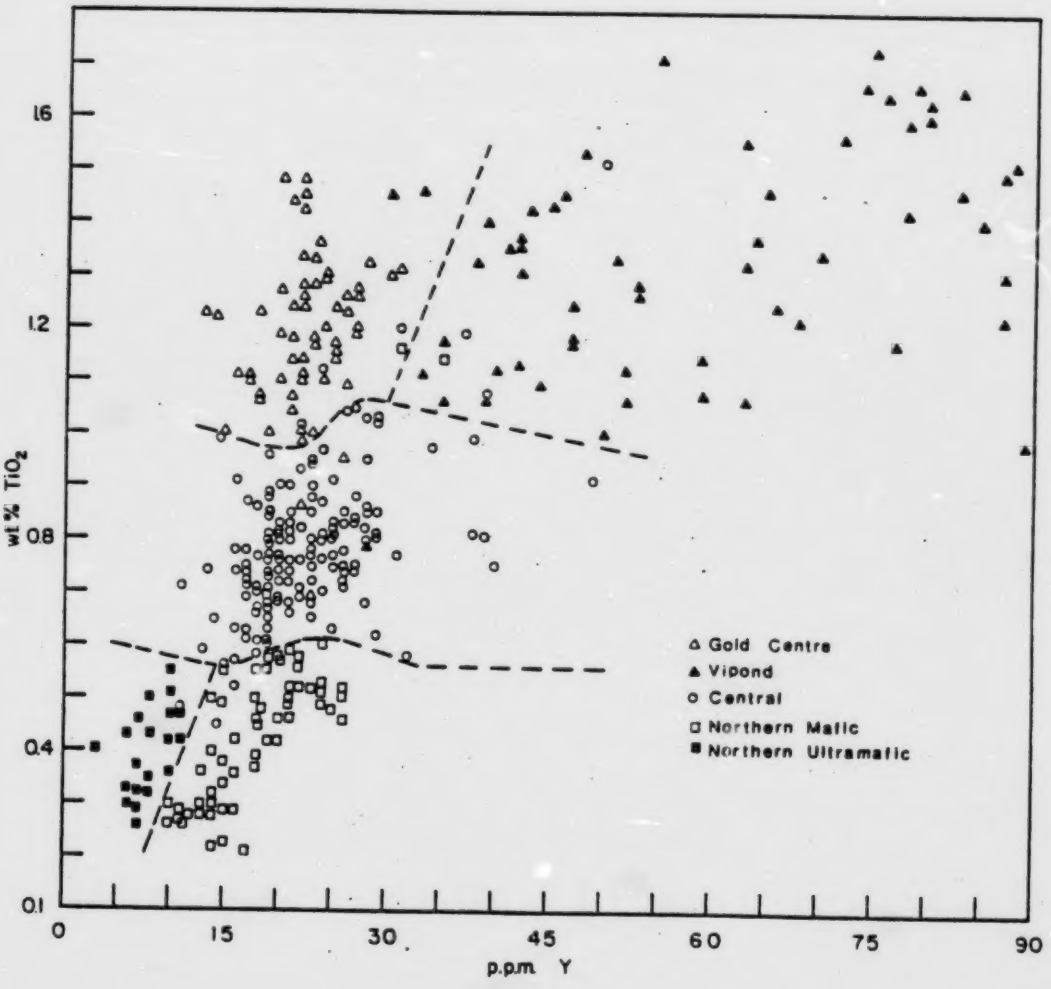

Figure 3. Binary immobile element (TiO_2-Y) plot of volcanic rocks from the 4 sub-groups of the Tisdale Group.

Central Tisdale Anticline (CTA), questioned by Karvinen (1978), and the Gillies Lake Fault (GLF) have been presented elsewhere (Davies and Whitehead, 1980).

Carbonate Species, CO_2/CaO Molar Ratios, and Intensity of Carbonatization

The degree of carbonate alteration is commonly expressed in terms of the CO_2 content of altered rocks. A more rigid interpretation is that CO_2 content measures the quantity of carbonate present but reveals little or nothing about the intensity of the carbonatization process. On the other hand, variations in carbonate mineral compositions and carbonate species zoning, for example ankerite or dolomite adjacent to veins grading to calcite outward from veins, result from changes in f_{CO_2} and intensity of CO_2 metasomatism.

Carbonatization is not only dependent on the availability of Ca, Mg and Fe in silicate minerals but is also a function of T and f_{CO_2}. Studies by Billings and White (1950) and Harte and Graham (1975) clearly indicate that in rocks of basaltic composition containing actinolite, chlorite and epidote, calcite forms before dolomite or ankerite and at lower mole fraction, X_{CO_2}, than that required to form the latter species. Harte and Graham (1975) discuss reactions of the types listed below.

(1) $3Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2 + 2Ca_2Al_3Si_3O_{12}(OH) + 10CO_2 + 8H_2O$
actinolite 'epidote'

$= 3(Mg,Fe)_5Al_2Si_3O_{10}(OH)_8 + 10CaCO_3 + 21SiO_2$
chlorite calcite

(2) $19Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2 + 6Ca_2Al_3Si_3O_{12}(OH) + 100CO_2 + 14H_2O$
actinolite 'epidote'

$= 9(Mg,Fe)_5Al_2Si_3O_{10}(OH)_8 + 50Ca(Mg,Fe)(CO_3)_2 + 143SiO_2$
chlorite ankerite

(3) $3(Mg,Fe)_5Al_2Si_3O_{10}(OH)_8 + 19CaCO_3 + 11CO_2$
chlorite calcite

$= 15Ca(Mg,Fe)(CO_3)_2 + 2Ca_2Al_3Si_3O_{12}(OH) + 3SiO_2 + 11H_2O$
ankerite 'epidote'

(4) $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 7CO_2$
actinolite calcite

$= 5Ca(Mg,Fe)(CO_3)_2 + 8SiO_2 + H_2O$
ankerite

The data of Skippen (1971) suggest a similar relationship between calcite-dolomite and f_{CO_2}/f_{H_2O} for rocks of ultramafic composition. However, because ultramafic rocks contain different silicate minerals (eg. serpentine, talc, tremolite) than metabasalts (eg. actinolite, chlorite, epidote) the T-X_{CO_2} conditions necessary to form a particular carbonate species will differ for the two rock types.

It is difficult to directly determine the proportions of individual carbonate species in fine-grained rocks, particularly where hundreds of samples are involved. A reliable, rapid method of estimating relative intensity of carbonate alteration utilizes the CO_2/CaO molar ratios of carbonatized metabasalts. The molar ratio CO_2/CaO of pure calcite is 1, whereas that for dolomite and ankerite is 2. The relative proportions of calcite and dolomite (ankerite) were determined for several dozen

samples by X-ray diffraction and the results compared with the CO_2/CaO molar ratios of the same samples. Samples with CO_2/CaO < 1 contained only calcite as the carbonate species; because the ratio for pure calcite is 1, some of the CaO in these samples must remain in silicate form. In samples where ratios equal 1, all or most of the CaO exists as calcite; little dolomite or ankerite was detected in these samples. A CO_2/CaO ratio of 1 represents CO_2 saturation relative to CaO. Ratios between 1 and 2 contained mixtures of calcite and ankerite or dolomite. At ratios equal to 2 only dolomite (ankerite) was present. Several samples have ratios in excess of 2. Mixtures of dolomite or ankerite with magnesite or siderite would produce these large ratios. Alternatively, ferroan ankerite in which Fe^{+2} substitutes for Ca^{+2} can produce ratios greater than 2. Deer, Howie and Zussman (1962, p.296) report an analysis of ferroan ankerite with a calculated ratio of 3.9. Samples of basalt from the test area with ratios greater than 2 gave no magnesite or siderite, but only ankerite (dolomite), peaks. It was concluded that ferroan ankerite probably was the dominant carbonate species in these samples.

The X-ray diffraction data confirm that CO_2/CaO molar ratios serve as a measure of the proportions of calcite and dolomite or ankerite in carbonatized metabasalts and therefore also as a measure of the intensity of carbonate alteration.

Figure 4 illustrates the relationship between CO_2 content and the CO_2/CaO molar ratios. The slopes of lines through the origin represent CaO contents. The amount of CO_2 taken up by the rock is controlled by

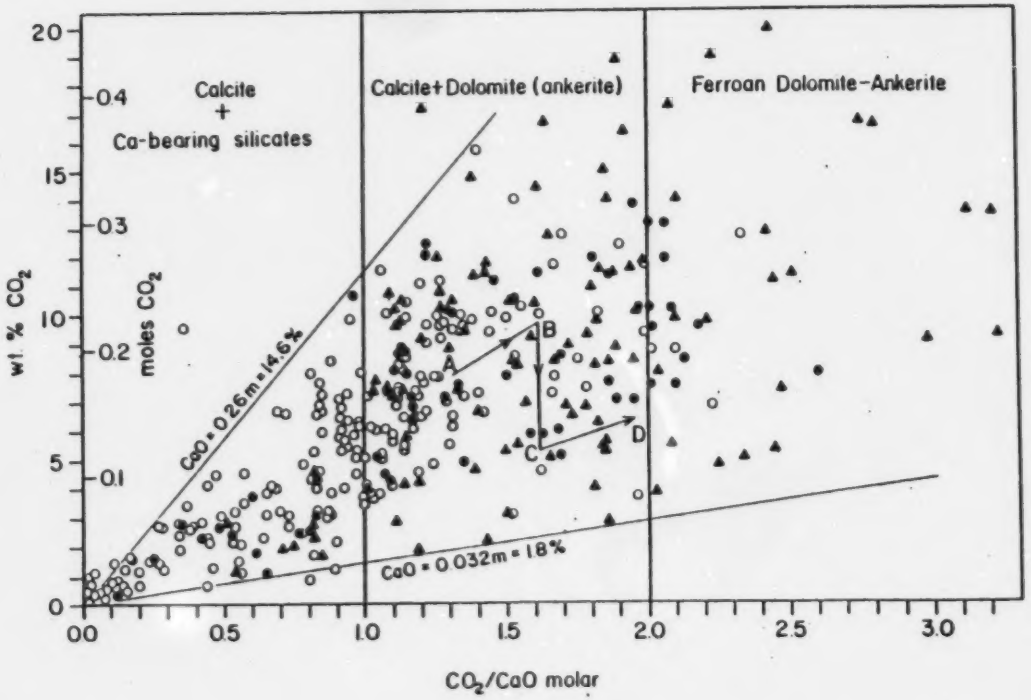

Figure 4. Plot of % CO_2 against CO_2/CaO Molar Ratio, sample of altered basalt, Timmins area. See text for significance of symbols.

both the CaO content and f_{CO_2}, which determines whether calcite or dolomite (ankerite) forms. At any particular CO_2/CaO ratio the CO_2 content can vary widely depending on the CaO content of the rock. On the other hand, at any specific % CO_2 the CO_2/CaO ratio can also vary greatly depending on the proportions of calcite to dolomite or ankerite in the rock. This results from the progressive alteration first to calcite and subsequently, at higher f_{CO_2}, to dolomite (ankerite). The path of alteration of a rock with a given CaO content will follow the sloping line, from the origin, representing that % CaO (eg. A-B, Figure 4). Addition of CaO or its removal at any stage in the alteration process will only affect the quantity of carbonate formed but not the CO_2/CaO ratio, provided f_{CO_2} remains relatively constant. The path will change in a vertical to near vertical direction (eg. B-C) and continued alteration will follow the sloping line representing the changed CaO content of the rock (eg. C-D).

On Figure 4 "mineralized" samples (solid circles and triangles) are distinguished from "unmineralized" (open circles). The proportion of "mineralized" to "unmineralized" samples increases as the CO_2/CaO molar ratio increases. "Mineralized" samples are those situated not more than 150 meters from known gold mineralization.

Regional Carbonate, Alkali and As Levels

Contoured values of CO_2, CO_2/CaO, K_2O, Rb, Na_2O and As for the Timmins area are presented in Figures 5 to 10. CO_2, CO_2/CaO, K_2O, Rb and As levels are distinctly greater in the vicinity of major gold mines than in the northern unmineralized parts of the area. Unlike K_2O and Rb, Na_2O is similar in both parts of the area and appears to offer little promise as a feature useful in selecting large areas for gold exploration. Contours of % CO_2 (Fig. 5) and CO_2/CaO (Fig. 6) appear to be equally effective in distinguishing mineralized from unmineralized parts of the Timmins area. However, within the mineralized part CO_2/CaO more clearly defines local targets.

Comparison of frequency plots (Fig. 11), means and standard deviations (Table 1) of data from the unmineralized control areas and the entire test area reveal significant differences in intensity of carbonate alteration (CO_2/CaO) and As abundance. Large parts of the Timmins area have experienced an overall enrichment in CO_2 and As (indicated by CO_2/CaO greater than about 0.75 and As abundances greater than 1 ppm). Most of this enrichment has been in the mineralized part of the Timmins area, between the Destor-Porcupine and Gillies Lake faults.

There are no significant differences in the average K_2O and Rb levels of the mineralized test area and unmineralized control areas. This suggests that there was no wholesale addition of these alkalies from external sources into the rocks of the Timmins area which, consequently, cannot be regarded

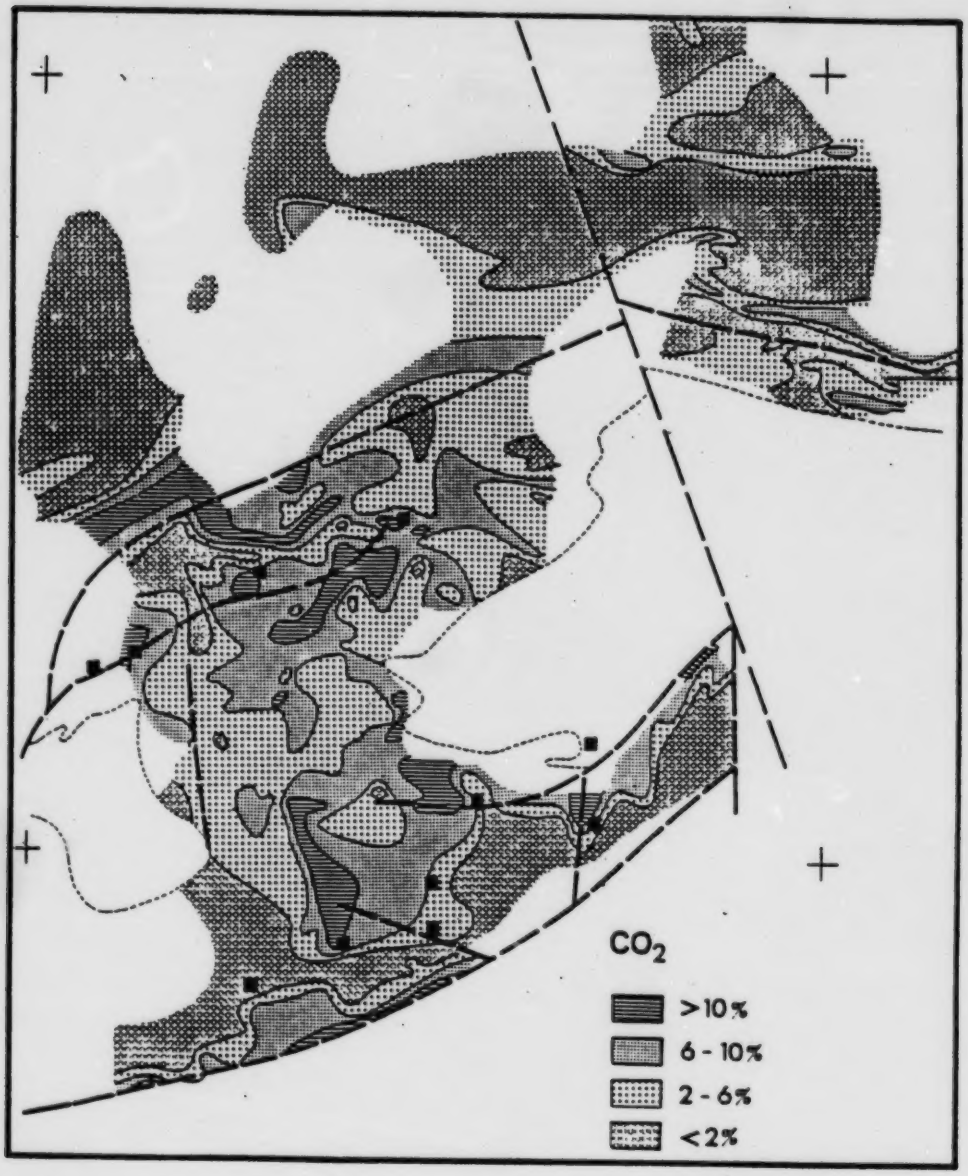

Figure 5. Contours of % CO_2, Timmins District.

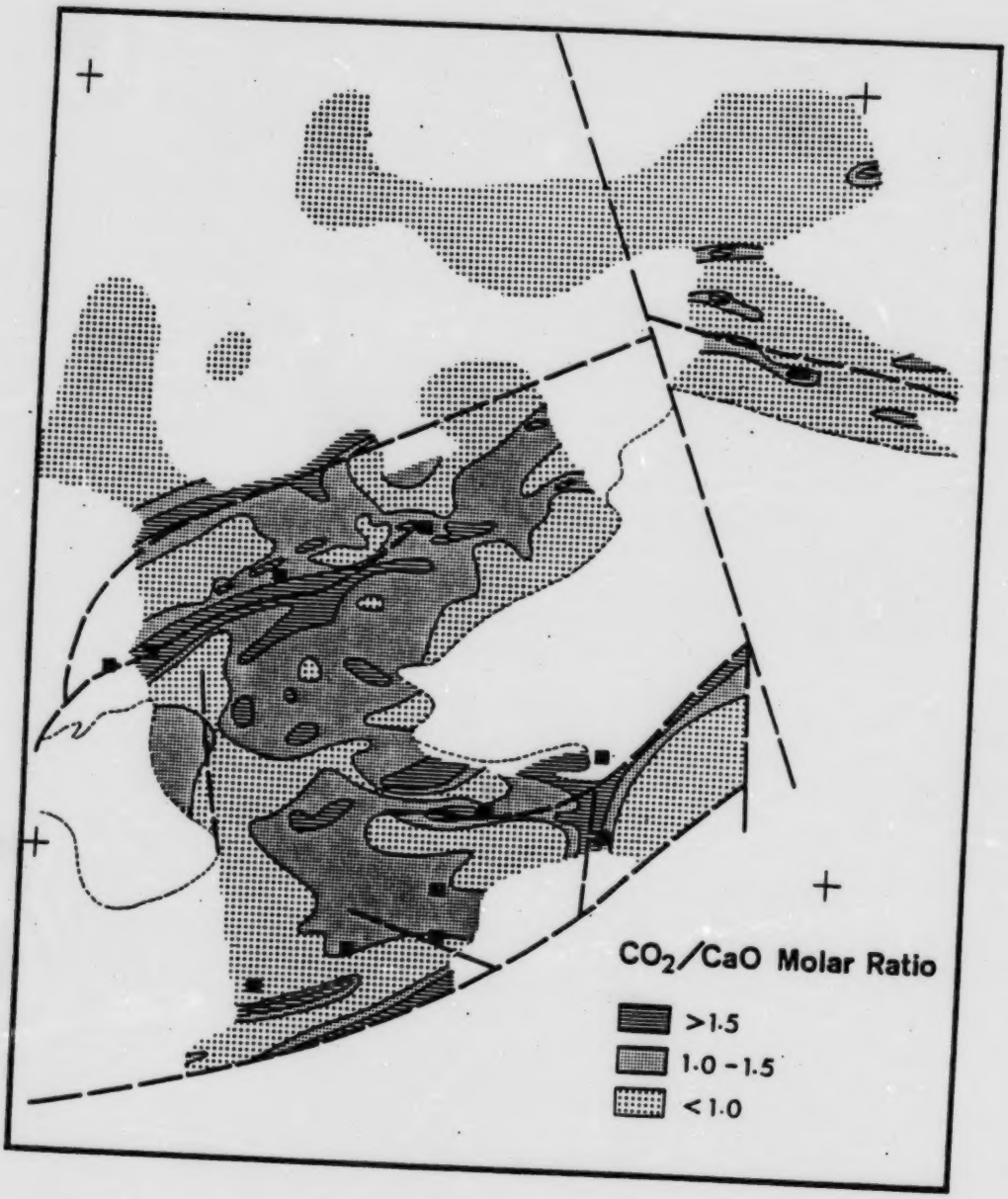

Figure 6. Contours of CO_2/CaO Molar Ratios, Timmins District.

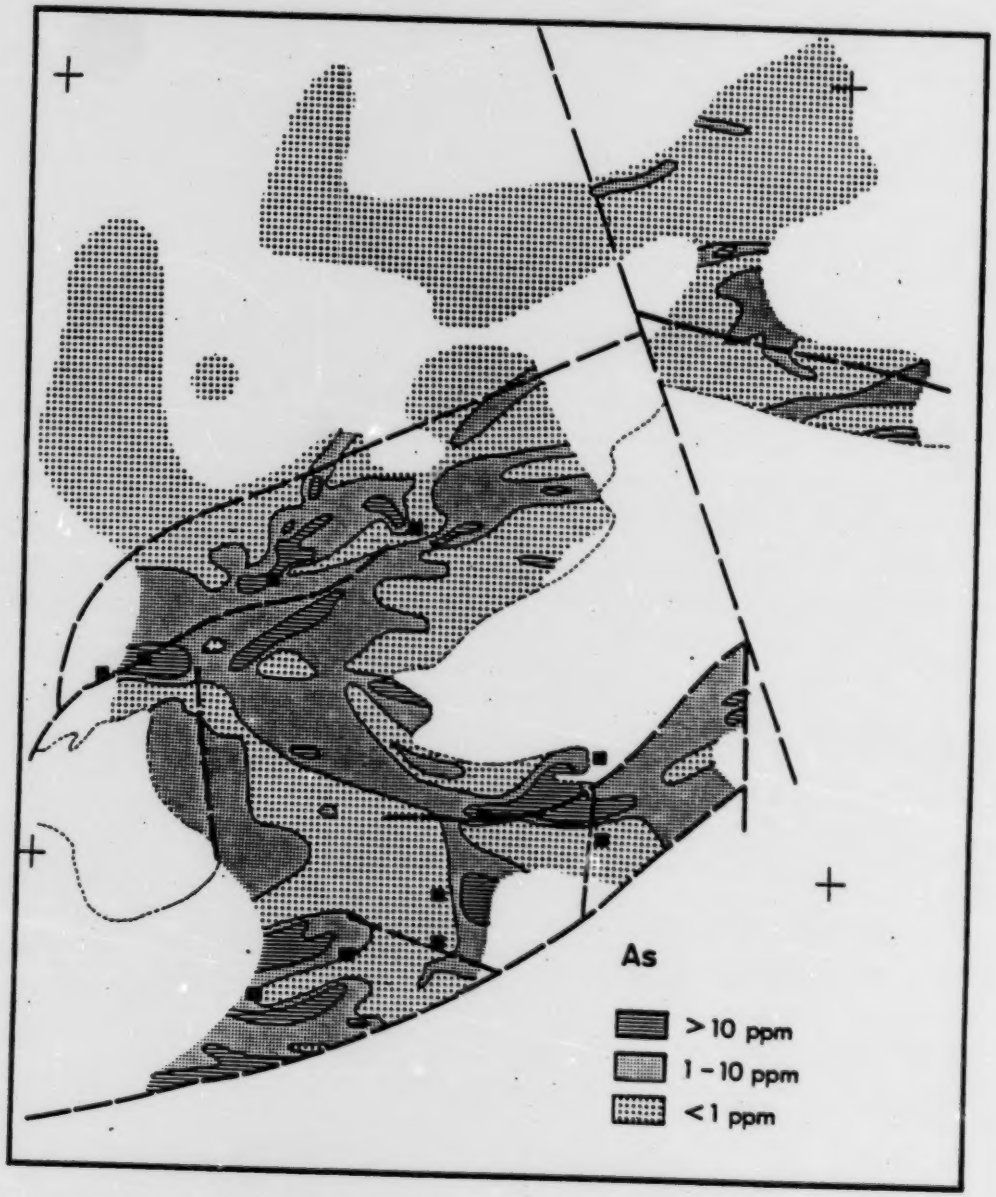

Figure 7. Contours of ppm As, Timmins District.

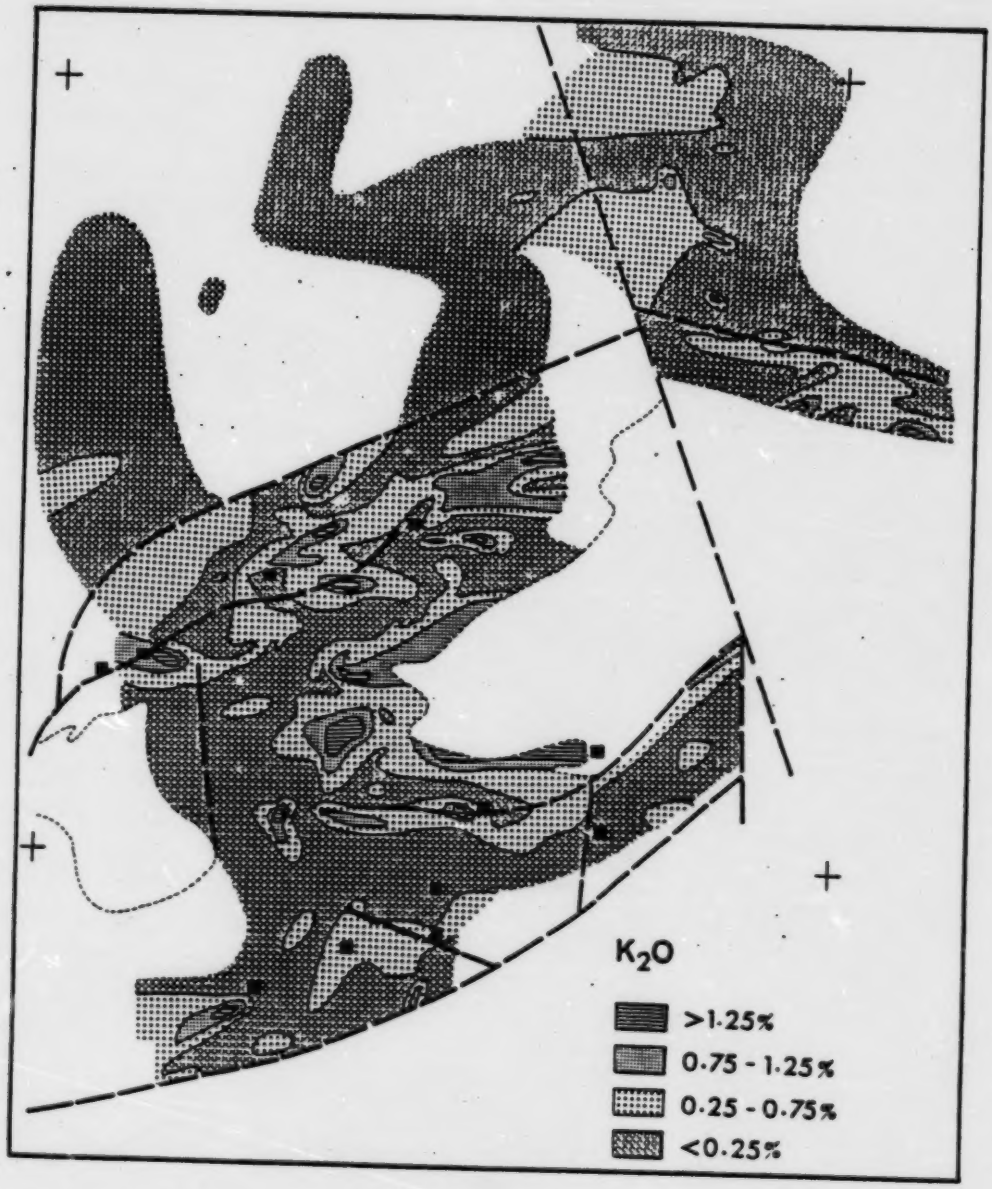

Figure 8. Contours of % K_2O, Timmins District.

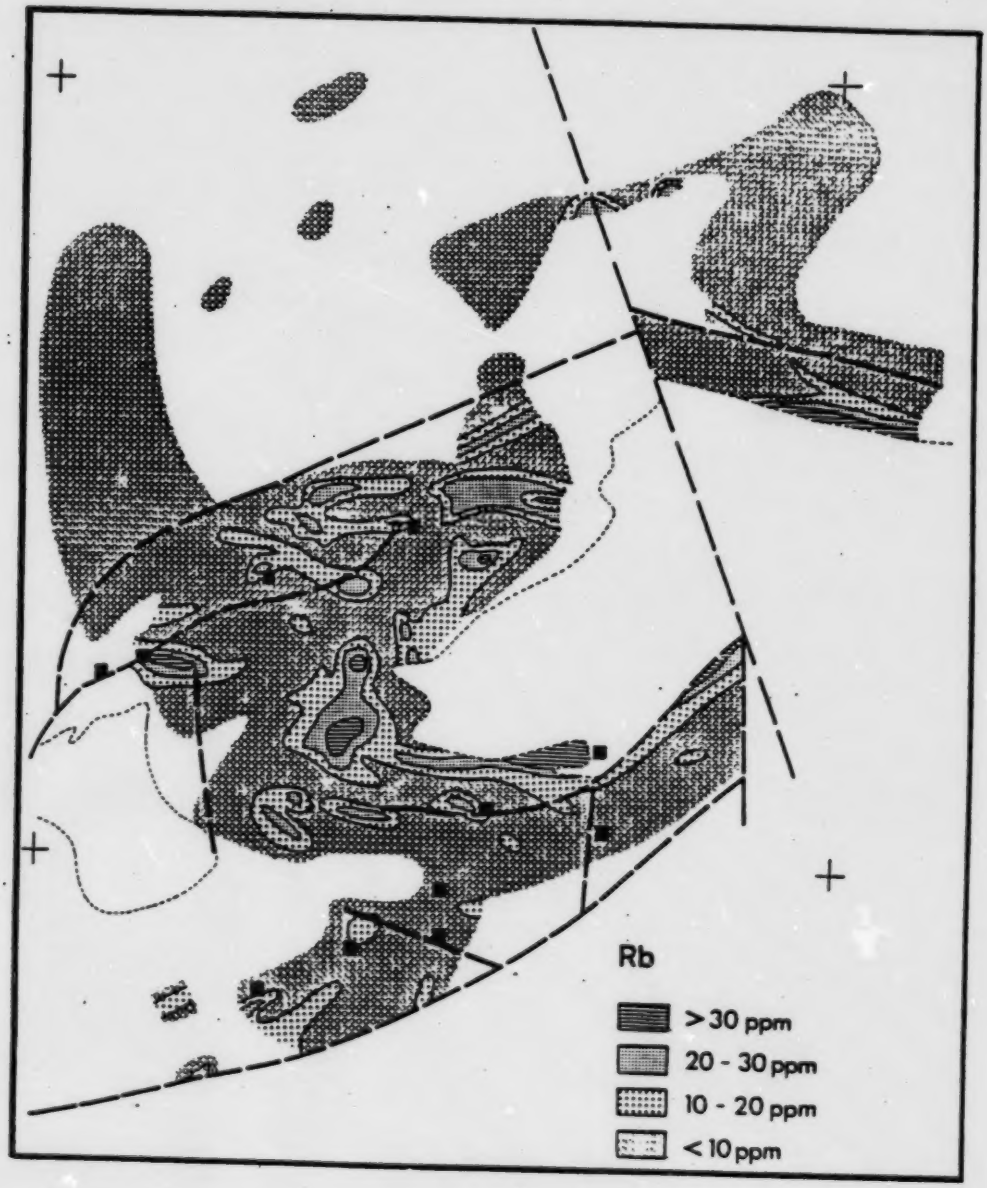

Figure 9. Contours of ppm Rb, Timmins District.

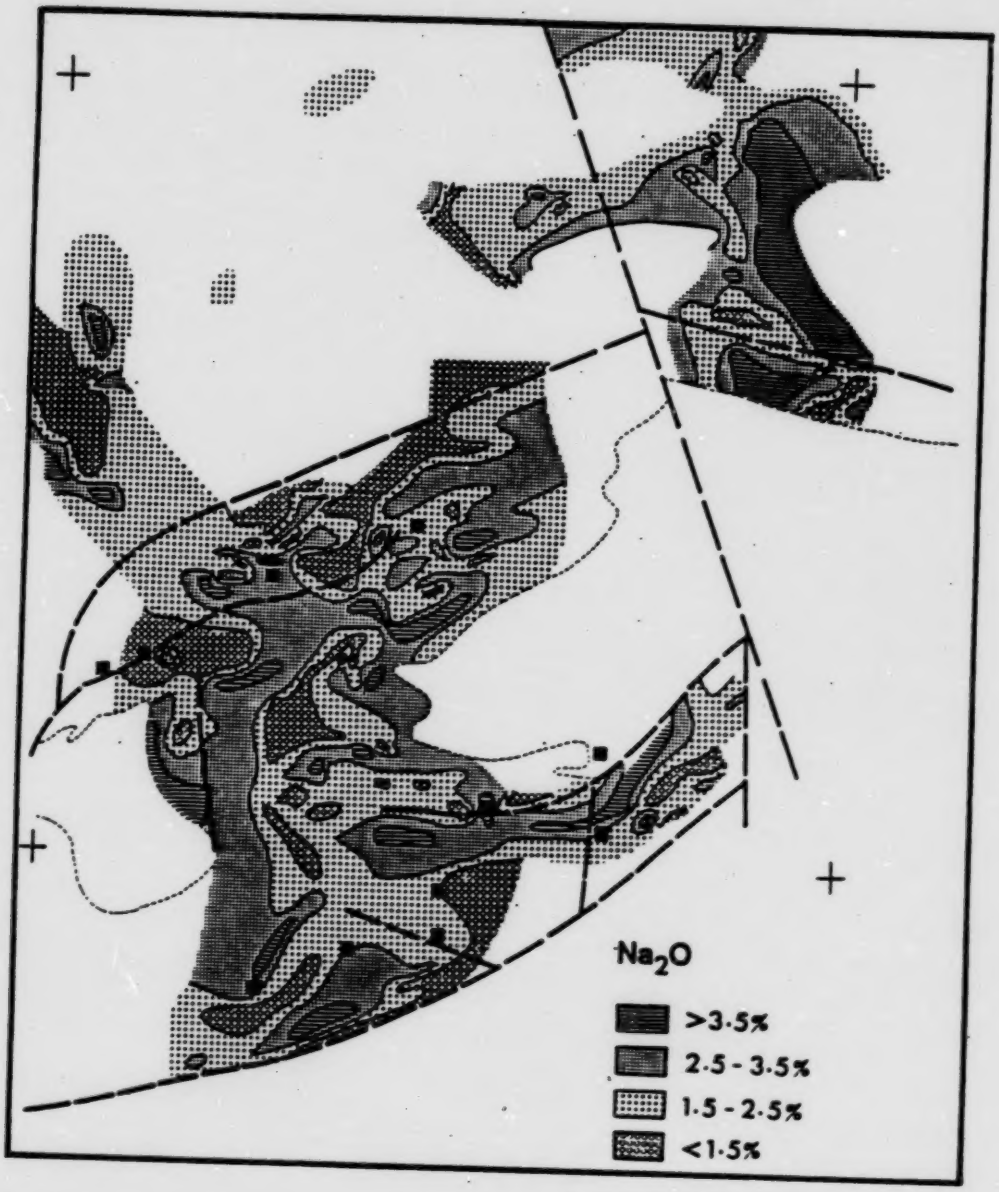

Figure 10. Contours of % Na_2O, Timmins District.

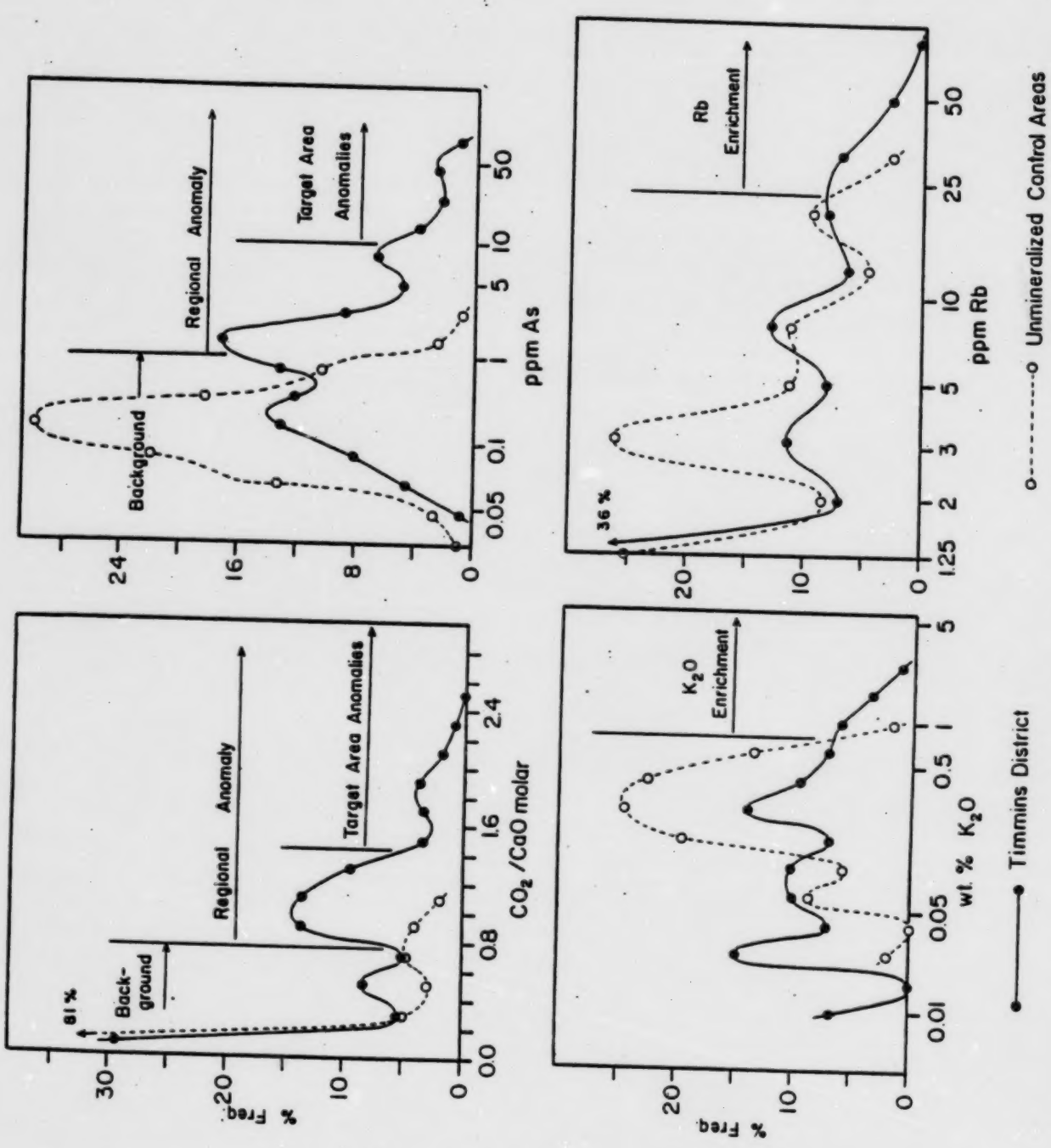

Figure 11. Frequency Distribution Plots of CO_2/CaO, As, K_2O and Rb from the mineralized Timmins District and Unmineralized Control Areas. The CO_2/CaO ratios are arithmetic; K_2O, As and Rb are logarithmic.

as anomalous in K_2O and Rb relative to the unmineralized control areas. The nature of the frequency distributions (Fig. 11) indicates remobilization of K_2O and Rb, with areas of enrichment and depletion throughout the Timmins district. The most extensive remobilization of K_2O and Rb appears to have occurred in association with intense CO_2 alteration (Figs. 8, 9). It should be noted that Rb has been remobilized even under conditions of low-grade regional metamorphism in the unmineralized control areas.

Target Anomalies

Estimated threshold values defining target anomalies are $CO_2/CaO = 1.5$ and As = 10 ppm (Fig. 11). These values and the regional thresholds values of $CO_2/CaO = 0.75$ and 1 ppm As correspond to the contoured intervals on Figures 6 and 7 with one exception. The exception is that the more conservative value $CO_2/CaO = 1$, marking CO_2 saturation relative to calcite, is used in place of $CO_2/CaO = 0.75$. The selected local threshold values of 0.75% K_2O and 20 ppm Rb may require some modification for particular lithologies within the Tisdale group as discussed below. The immobile trace element data (Fig. 3) indicate increasing fractionation (and possible corresponding higher original K_2O and Rb contents) stratigraphically upward from the basal Northern to the Gold Centre Sub-group.

Table 2 presents data for less altered, $CO_2/CaO < 0.75$, and more altered, $CO_2/CaO > 0.75$, samples of each Sub-group of the Tisdale Group. The K_2O and Rb contents of less altered samples from the Northern Sub-group are lower than those in the other 3 Sub-groups which all have similar mean

	Unmineralized(Control) Areas			Mineralized Timmins Area		
	n	mean	S.D.	n	mean	S.D.
CO_2/CaO *	99	0.133	0.266	372	0.67	0.67
ppm As	113	0.33	0.31	386	4.02	10.64
% K_2O	101	0.28	0.20	425	0.33	0.47
ppm Rb	101	6.53	6.96	453	8.20	11.4

* Excludes ultramafic rocks.

Table 1. Means and Standard Deviation, Unmineralized Control Areas and Mineralized Timmins Area.

K_2O and Rb contents. The proposed threshold values of 0.75% K_2O and 20 ppm Rb are conservative for the Central, Vipond, and Gold Centre Sub-groups but are too high for rocks of the Northern Sub-group. Consequently some target area anomalies in this Sub-group may not be detected using only K_2O and Rb.

The mean K_2O and Rb contents in the majority of less altered rocks are comparable to the mean contents obtained for the unmineralized control areas. The mean As contents of the less altered samples of all sub-groups are 3 to 5 times higher than the mean for the unmineralized areas, confirming the presence of pervasive As enrichment throughout the entire mineralized area. The recommended target threshold of 10 ppm As is conservative and levels between 1 and 10 ppm in association with $CO_2/CaO > 1.5$ are characteristic of some target areas. These As contents are much lower than the threshold of 70 ppm recommended by Fyon and Crockett (1979) for some of the tholeiitic volcanic rocks of the Timmins area.

The more altered samples of basalts from all sub-groups are enriched in K_2O, Rb and As 2 to 5 times relative to their less altered equivalents. This demonstrates a general correlation between K_2O, Rb and As enrichment and intensity of carbonate alteration.

Target anomalies on Figure 12 have been extracted from Figures 6, 7, 8 and 9. A reasonably good spatial correlation exists among the 4 types of anomalies as well as between them and such known mineralized areas as Hollinger, Pamour-Schumacher, Coniaurum, Dome and Paymaster-Tisdale. Even several small gold properties in the northeast quarter of Tisdale

	Less Altered ($CO_2/CaO < 0.75$)						More Altered ($CO_2/CaO > 0.75$					
	% K_2O		ppm Rb		ppm As		% K_2O		ppm Rb		ppm As	
	n	mean (S.D.)	n	mean (S.D.)	n	mean (S.D.)	n	mean (S.D.)	n	mean (S.D.)	n	mean (S.D
Gold Centre	11	0.28(0.25)	11	7.5(6.6)	8	1.0(0.5)	32	0.62(0.53)	32	16.5(12.9)	31	4.9(14.6)
Vipond	28	0.15(0.19)	30	4.0(5.0)	26	1.5(2.6)	52	0.46(0.52)	51	11.7(14.5)	48	7.0(13.9)
Central	90	0.23(0.39)	91	5.1(8.6)	84	2.3(3.9)	104	0.38(0.44)	99	10.5(12.5)	97	6.4(12.9)
Northern Mafic	44	0.10(0.17)	44	2.1(2.5)	37	0.88(2.02)	10	0.63(0.51)	10	15.3(11.9)	9	20.2(27.7
Northern Ultramafic	11	0.03(0.03)	11	2.0(1.5)	5	1.5(2.5)	5	0.01(0.01)	5	0.8(1.1)	2	13.7(18.8

Table 2. K_2O, Rb, As contents related to intensity of alteration in the Sub-groups of the Tisdale Group.

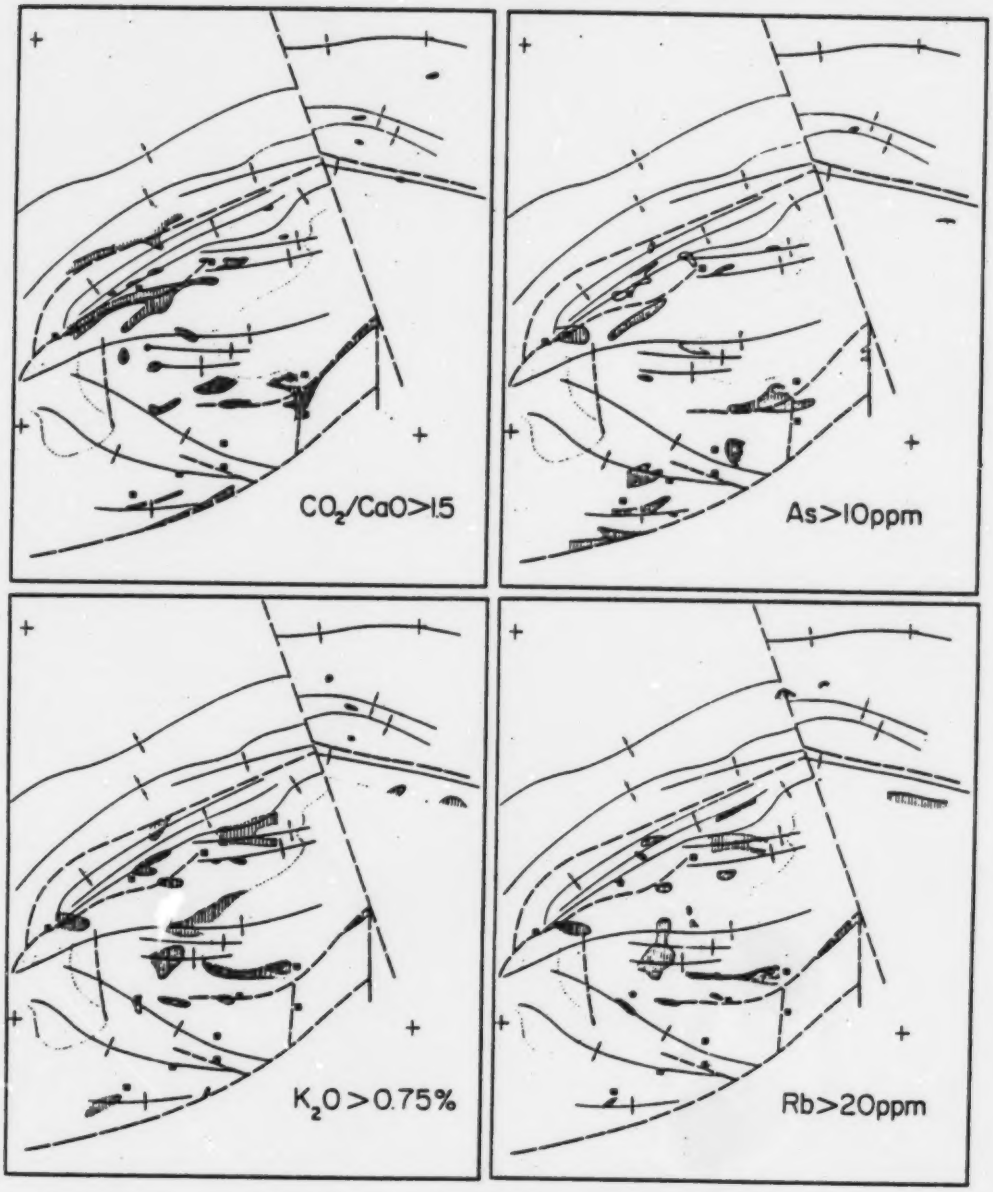

Figure 12. Local CO_2/CaO, As, K_2O and Rb Anomalies, Timmins District.

township can be detected. On the other hand, coincident anomalies of all 4 types are not associated with the Buffalo-Ankerite, Paymaster-Deloro or Aunor mines. As implied above and demonstrated below, combinations of values, one or more of which may be below the designated threshold, are also significant.

Other groups of coincident anomalies such as those around the nose of the Porcupine syncline, along the Destor-Porcupine fault, and along the Gillies Lake fault are not known to be associated with important gold occurrences. However, these areas are worthy of further investigation. Two small As anomalies east of the Dome Mine are situated in an area of low K_2O, Rb and CO_2/CaO ratios; these may be spurious and the result of surface contamination.

A test of the confidence to be placed in the selected threshold values, and of the significance of anomalies in terms of gold occurrences, is afforded by considering a group of samples from wall-rocks surrounding veins in the Dome and Pamour #1 mines. Detailed profiles (Fig. 13) illustrate the CO_2/CaO, As and K_2O values directly associated with gold-bearing veins. The Dome traverse trends south through tholeiitic basalts of the Gold Centre (0-90 meters) and Vipond Sub-groups (90-300 meters). This section contains a few quartz veins and several ankerite veins some of which cross-cut the flows and some of which lie along flow contacts. The entire Dome section is heavily carbonatized, $CO_2/CaO > 1$, and the southerly portion from 165 to 300 meters is very intensely altered, CO_2/CaO 1.2 to 3.5. In similar fashion the section from 145 to 300 meters is strongly

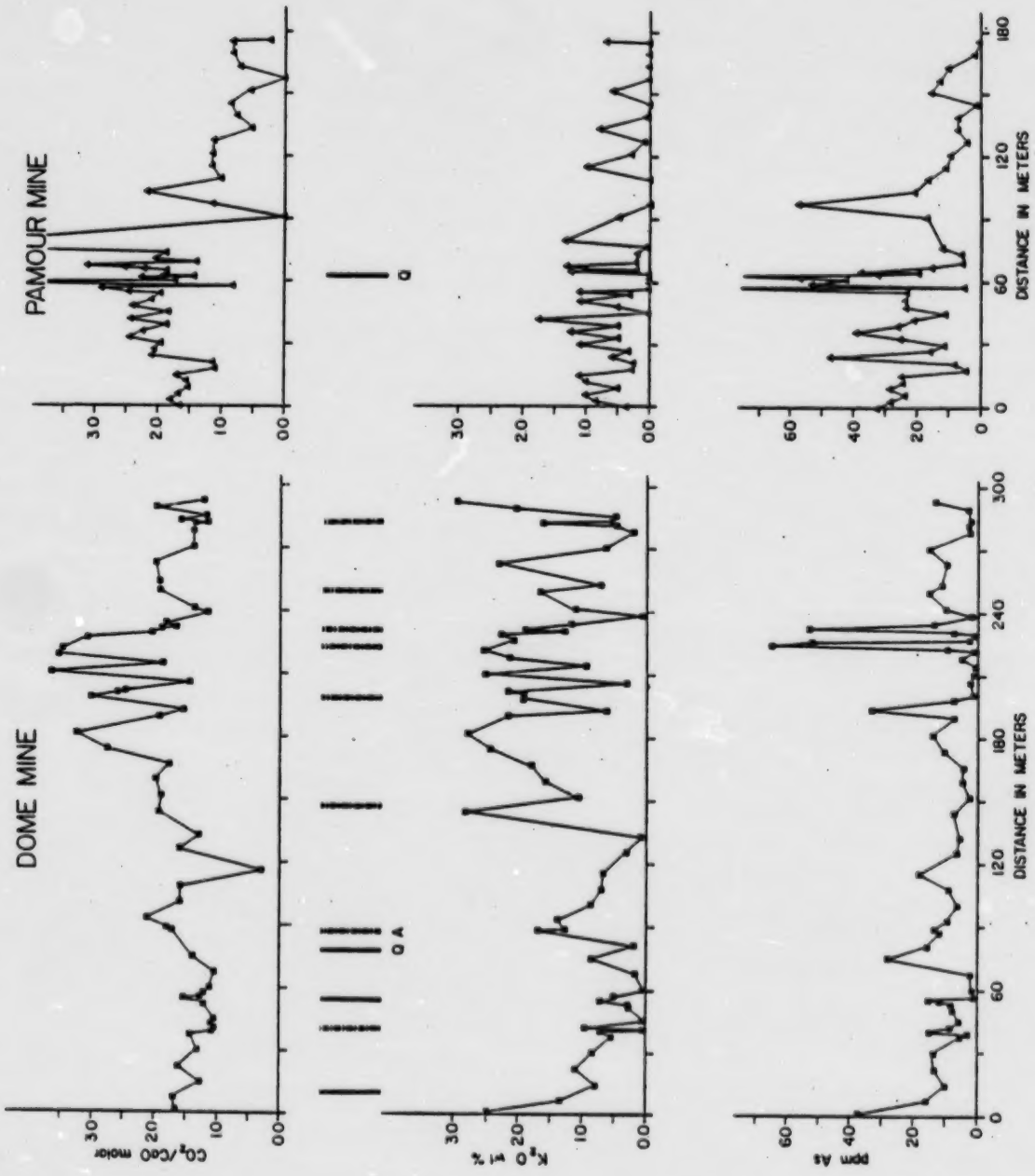

Figure 13. Profile of CO_2/CaO, As, and K_2O, Dome and Pamour Mines. Q refers to quartz veins; A refers to "ankerite" veins, Dome Mine only.

Category	Number	% of total
$CO_2/CaO < 1$	10	9%
CO_2/CaO 1-1.5	32	28.8
$CO_2/CaO > 1.5$	69	62.2
As < 1 ppm	6	5.4
As 1-10	45	40.5
As > 10	60	54.1
$K_2O < 0.75$ %	61	54.9
$K_2O > 0.75$	50	45.1

Table 3. Classification of 111 "mineralized" samples directly associated with gold-bearing veins at Dome and Pamour #1 mines.

enriched in K_2O (up to 2.5%). Most of the high As values (up to 65 ppm) are found in the southernmost section (210 to 240 meters) where CO_2/CaO and K_2O are also high.

The Pamour traverse cuts magnesian basalts of the Northern Sub-group. The K_2O values are somewhat lower than at Dome, possibly reflecting the lower initial K_2O content of the Northern Sub-group (Table 2). CO_2/CaO values are comparable to those at Dome but the As abundances are considerably higher at Pamour #1.

Plots of As and K_2O against CO_2/CaO for the mine samples are presented in Figures 14 and 15. Table 3 summarizes the data by categories of increasing CO_2/CaO, As and K_2O. It is apparent that there is a progressive increase in the percentage of samples with higher CO_2/CaO and As. No such increase occurs in relation to K_2O, for this group of samples. The probable reason is that about half of the samples are from the Northern Sub-group which has an initially lower K_2O content than the other Sub-groups (Table 2). It is significant that not more than 60% of samples closely associated with gold can be expected to exceed the CO_2/CaO threshold of 1.5, nor about 50% to exceed the 10 ppm As and, perhaps, the 0.75% K_2O thresholds.

Figures 16 and 17 are plots of As and K_2O against CO_2/CaO for the surface samples collected throughout the Timmins area. "Mineralized" samples (solid circles) are arbitrarily defined as those taken within 150 meters of known gold-bearing quartz veins. Those taken outside this limit are represented by open circles. Many "mineralized" samples have values below the thresholds selected for As (10 ppm), K_2O (0.75%) and

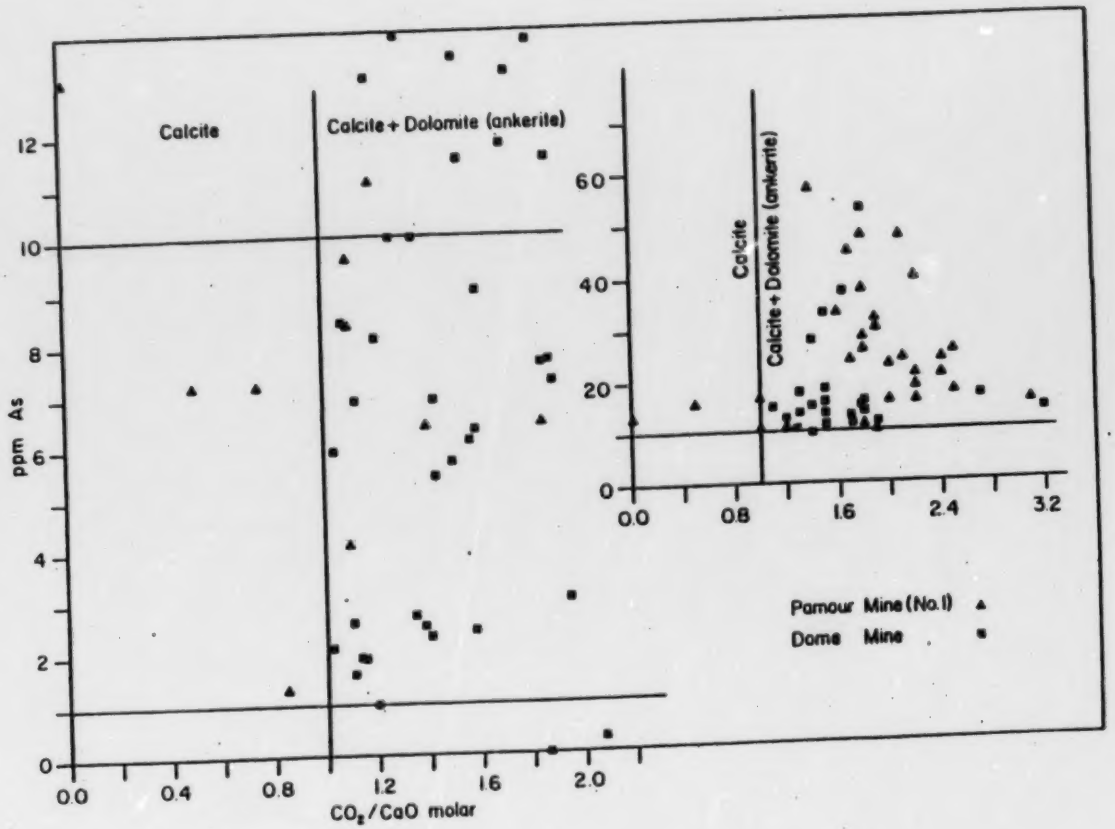

Figure 14. Plot of As against CO_2/CaO, Pamour #1 and Dome Mines. All samples are associated with gold mineralization.

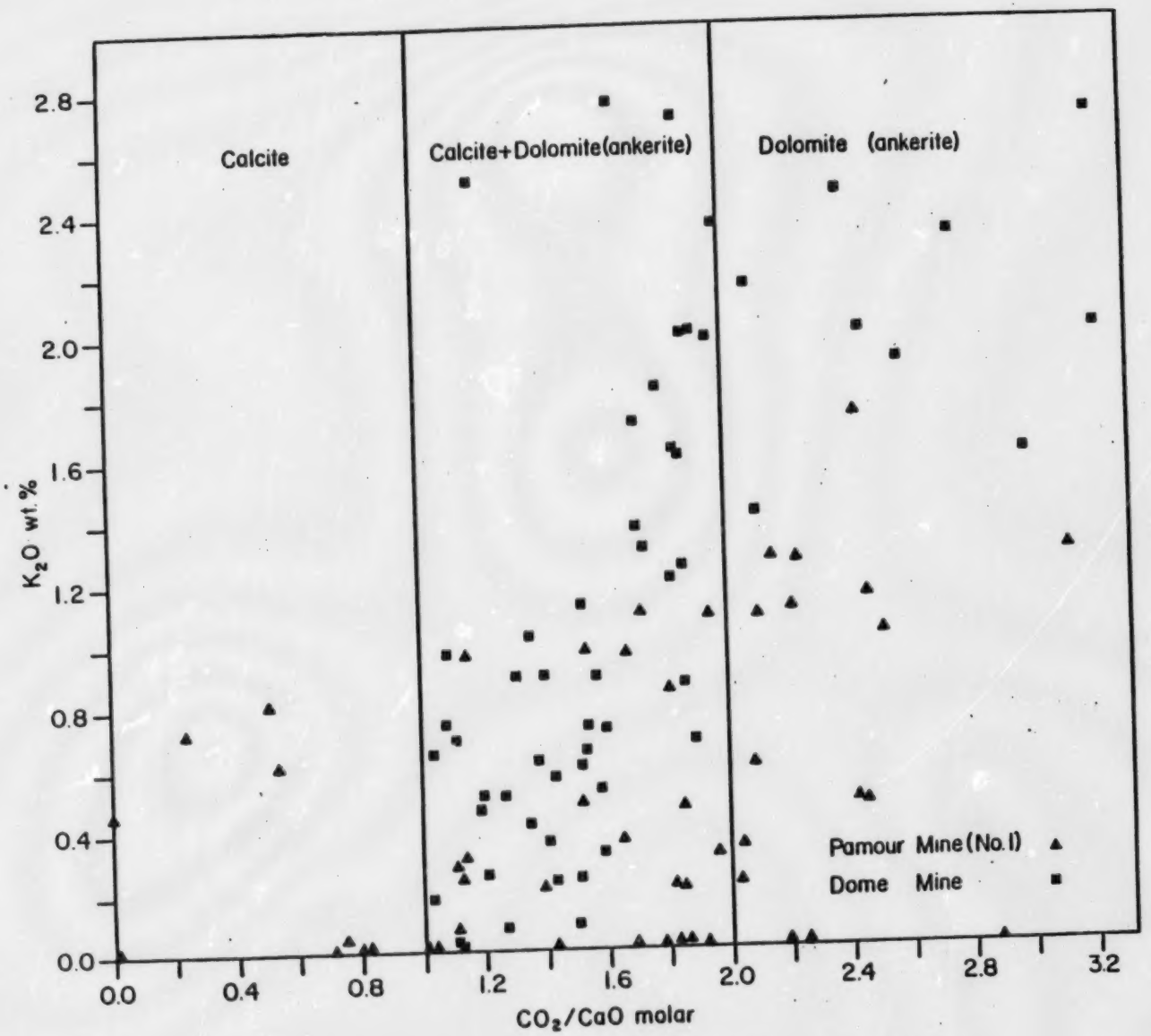

Figure 15. Plot of K_2O against CO_2/CaO, Pamour #1 and Dome Mines. All samples are associated with gold mineralization.

Category	Total Samples	Mineralized Samples	% Mineralized
$CO_2/CaO < 1$	248	20	8.1
CO_2/CaO 1-1.5	98	24	24.5
$CO_2/CaO > 1.5$	52	26	50.0
As < 1 ppm	182	24	13.2
As 1-10	129	25	19.4
As > 10	41	17	41.5
$K_2O < 0.75\%$	361	50	13.8
$K_2O > 0.75$	58	19	32.8

Table 4. CO_2/CaO, K_2O, As levels relative to Gold Mineralization, Surface Samples Timmins District.

Category	Sub-Category	Total Samples	Mineralized Samples	% Mineralized
$CO_2/CaO < 1$	$K_2O < 0.75\%$	221	19	8.6
	$K_2O > 0.75$	18	1	5.6
CO_2/CaO 1.0-1.5	$K_2O < 0.75$	87	18	20.7
	$K_2O > 0.75$	11	6	54.5
$CO_2/CaO > 1.5$	$K_2O < 0.75$	30	13	43.3
	$K_2O > 0.75$	20	13	65.0
$CO_2/CaO < 1$	As < 1 ppm	132	7	5.3
	As 1-10	63	6	9.5
	As > 10	14	3	21.4
CO_2/CaO 1.0-1.5	As < 1	36	11	30.6
	As 1-10	46	9	19.6
	As > 10	8	4	50.0
$CO_2/CaO > 1.5$	As < 1	12	6	50.0
	As 1-10	15	9	60.0
	As > 10	18	10	55.6
$K_2O < 0.75\%$	As < 1	147	17	11.6
	As 1-10	114	19	16.7
	As > 10	29	8	27.6
$K_2O > 0.75\%$	As < 1	21	6	28.6
	As 1-10	15	4	26.7
	As > 10	12	8	66.7

Table 5. Combinations of CO_2/CaO, K_2O, As (Category and Sub-category) relative to Gold Mineralization, Surface Samples, Timmins District.

CO_2/CaO (1.5). In view of the results from the Dome and Pamour mines, this is not unexpected. In addition, many "unmineralized" samples have As, K_2O and CO_2/CaO above threshold. However, the proportions of "mineralized" to "unmineralized" samples is much greater at higher CO_2/CaO, As and K_2O values (Table 4).

It appears that the best single indicator of proximity to gold occurrences is the CO_2/CaO molar ratio. Arsenic by itself is less effective than CO_2/CaO, and K_2O alone is still less effective. However, K_2O and As in combination either with one another or with CO_2/CaO (Table 5) add a further degree of discrimination between "mineralized" and "unmineralized" samples. This is particularly significant in the category CO_2/CaO 1 to 1.5 where 24.5% of the samples are mineralized (Table 4). Dividing these into sub-categories (Table 5) with K_2O greater and less than 0.75% reveals that 54.5% of the samples with $K_2O > 0.75\%$ and CO_2/CaO 1 to 1.5 are mineralized. A less marked increase in percentage of samples that are mineralized occurs when considering K_2O and As in the category $CO_2/CaO > 1.5$. The data of Table 5 also reveal that 67% of those samples containing more than 0.75% K_2O and 10 ppm As are mineralized, regardless of CO_2/CaO. Not shown on Table 5 are combinations involving all 3 measurements: CO_2/CaO, As, and K_2O. Only 9 samples contained coincident values above the thresholds for these 3 parameters; 6 (67%) of these samples were associated with known mineralization. In general $CO_2/CaO > 1$, $K_2O > 0.75$ and As > 10 ppm, in appropriate combinations, suggest a 50% to 67% probability of proximity to gold occurrences. That these expectations are realistic maxima is supported by the % distribution of CO_2/CaO, As and K_2O values from the mine samples (Table 3), all of which are mineralized.

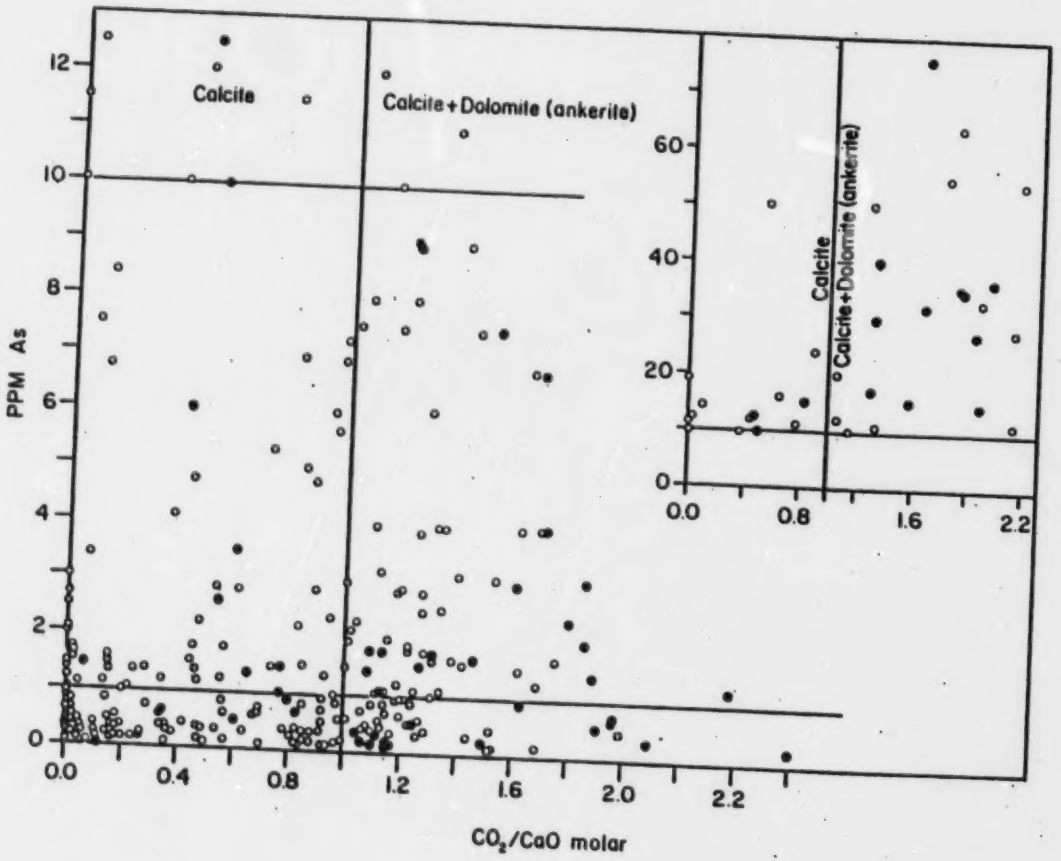

Figure 16. Plot of As against CO_2/CaO, surface samples, Timmins District. Samples associated with know gold mineralization are shown by solid black circles.

Localization of Alteration and Gold Mineralization

Most of the recently proposed models of gold mineralization in the Timmins, Kirkland Lake and Larder Lake areas recognize, as did the early workers in these areas, the importance of carbonate alteration. Most recent models also invoke a two-stage process involving (1) initial concentration of gold and carbonate by synvolcanic or synsedimentary and pre-tectonic deposition, (2) subsequent syntectonic metamorphic remobilization and concentration to form "epigenetic" gold-bearing quartz veins. Differences in the various models relate mainly to the initial concentration of gold and carbonate, distribution of carbonate alteration and timing of the carbonatizing process.

Karvinen (1978, 1980) regards stratigraphically distributed, exhalative carbonate horizons and associated felsic porphyries as initial sources of carbonate and gold in the Timmins area. Fyon and Crockett (1980) note that carbonatized rocks occur throughout the volcanic stratigraphy of those portions of the Tisdale group studied by them. In some cases the alteration is described as stratabound and elsewhere as discordant; they present structural and textural arguments for a synvolcanic-pretectonic origin for the carbonatization.

Pyke (1976, 1980) emphasizes the role of major faults in localizing carbonate alteration. Komatiites which are very susceptible to alteration, and the location of which frequently coincides with that of major faults are regarded as the probable sources of gold. He suggests that CO_2 from sedimentary sources was remobilized during folding and focussed along faults,

altering the komatiites and releasing gold. Jensen (1980) also stresses the importance of major faults in localizing carbonatization and mineralization in the Kirkland Lake area. However, he regards basin-margin calcareous and carbonaceous sediments as the probable source of both CO_2 and Au. Downes (1980) supports the concept of post-volcanic or late syn-tectonic carbonatization. He reports unaltered ultramafic clasts in conglomerates overlying carbonatized volcanic rocks in the Kirkland Lake area. Downes also points out that the most commonly carbonatized rock type in that area is ultramafic, resulting in the stratigraphic appearance of the carbonatized zones.

The results of the present study on carbonate distribution and the earlier studies of volcanic stratigraphy and immobile trace element data (Davies, Grant and Whitehead 1979; Davies and Whitehead 1980) are difficult to reconcile with the concept of extensive, stratigraphically distributed and continuous carbonate horizons in the Timmins area. Both Karvinen (1980) and Fyon and Crockett (1980) recognize the locally transgressive nature of the carbonate. However, the degree of discordance of the "upper carbonate member" as mapped by Karvinen (1980) is extreme in some places. In the area of the Coniaurum and Pamour-Schumacher shafts (Figs. 1 and 2) this carbonate is shown following the lower contact of the Vipond Sub-group northeastward to just east of the Coniaurum shaft where it doubles back sharply through the shaft area and then extends southwest toward the Hollinger shaft. This path does coincide with a number of highly carbonatized locations (Fig. 6) but it transgresses from the bottom of the Vipond Sub-group stratigraphically downward to rocks of the middle or lower Central Sub-group.

The same "upper carbonate member" is shown following along the contact between the Vipond and Central Sub-group, outlining the limbs of the Vipond Anticline (VA, figure 1). The analytical data (Fig. 6) indicate that the highest intensity of carbonatization occurs in the core of the anticline ($CO_2/CaO > 1.5$). A broad zone of slightly less but still intense alteration, CO_2/CaO 1 to 1.5, blankets the entire area of Central and adjacent Vipond rocks, extending from the core of the fold to beyond both sides of the Vipond-Central contact. Consideration of carbonate alteration in terms of quantity (weight % CO_2, Fig. 5) rather than intensity (CO_2/CaO) does not resolve these difficulties in reconciling the analytical data with the concept of stratigraphic carbonate horizons.

The patterns of alteration in Figures 5 and 6 are strong evidence of large-scale regional pervasive carbonatization. Large areas with $CO_2 > 6\%$ and CO_2/CaO greater than 1, representing CO_2 supersaturation relative to calcite, cut across the entire stratigraphic sequence of the Tisdale group. Anomalies representing highest intensities of carbonatization ($CO_2/CaO > 1.5$) are distributed throughout all 4 Sub-groups in the area between the Gillies Lake and Destor-Porcupine faults. Most of them are not restricted to particular stratigraphic horizons. Some of the largest and most continuous anomalies do have a stratigraphic appearance but these occur mainly adjacent to faults and along zones of intense shearing which commonly are parallel or sub-parallel to flow contacts. Even parts of these are discordant. The one band of high CO_2/CaO not apparently related to shearing coincides with a Mg-rich flow south of the Aunor and Delnite shafts.

The spatial relationships between CO_2/CaO, As, K_2O and Rb anomalies and structures are summarized on Figure 12. Many of the anomalies that are not along fault zones coincide with fold axes and areas of strong schistosity. Perhaps more significant is the fact that the region of abundant anomalies and gold occurrences is largely restricted to the area between the Gillies Lake and Destor-Porcupine faults. This is an area of complex deformation caused by multiple folding the last stage of which is represented by the Porcupine syncline around which earlier folds have been re-oriented (Pyke, 1976; Davies, 1977).

Although there may be some synvolcanic, stratigraphically distributed carbonate in the area, the bulk of it cannot be identified as such. The present distribution and pattern of carbonatization and its relationship to volcanic stratigraphy and structure are strong evidence for syntectonic or late tectonic, post-depositional alteration. The patterns and distribution of extensive arsenic enrichment and remobilized K_2O and Rb, corresponding to the carbonate alteration at both the regional and local scales, support this conclusion.

Application to Gold Exploration

The results of this study can be applied at various levels of detail in exploration for gold in basaltic rocks. At the reconnaissance level a sample density of about 10 sites per kilometer should distinguish large regions with high potential for gold occurrences from those with low potential. Sampling at this density need not be undertaken indiscriminantly over large

areas but should be based, in the first instance, on the presence of widespread megascopically visible carbonate alteration. Large areas (several square kilometers) with numerous CO_2/CaO values near 1 and As contents above 1 ppm can be considered favourable for more detailed exploration.

Preliminary indication of potential target areas (several thousand square meters in size) may be achieved with a sample spacing of 150 meters or less. Target areas can be identified by any of the following combinations of values:

CO_2/CaO 1-1.5 and > 1.5, K_2O > 0.75%

CO_2/CaO 1-1.5, As > 10 ppm

CO_2/CaO > 1.5, As < 1 to > 10 ppm

K_2O > 0.75%, As > 10 ppm

CO_2/CaO > 1.5, K_2O > 0.75%, As > 10 ppm

CO_2/CaO, As and K_2O can also be used effectively in detailed underground exploration using either stope and drift samples or diamond drill core. An example is presented in Figure 18. The line of samples, taken at 15-meter intervals along a cross-cut on the 1400-foot level at Pamour #1 mine, is located about 150 meters from gold-bearing quartz veins that occur on both sides of the sampled section (XYZ). Plots of CO_2/CaO, K_2O and As clearly identify points Y and Z as anomalous. These points lie on the projections between the east vein and the two west veins and the anomalies clearly indicate the existence of gold-bearing quartz veins along strike.

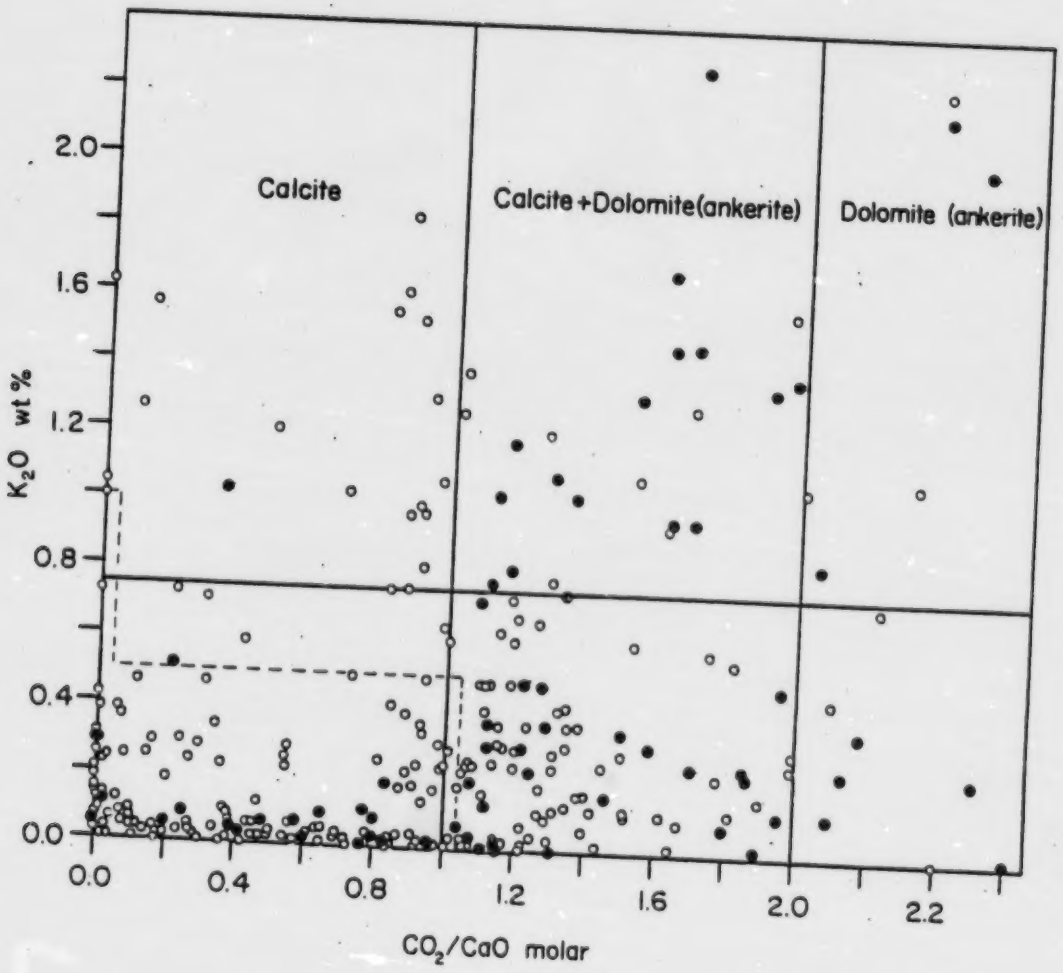

Figure 17. Plot of K_2O against CO_2/CaO, surface samples, Timmins District. Samples associated with known gold mineralization are shown by solid black circles.

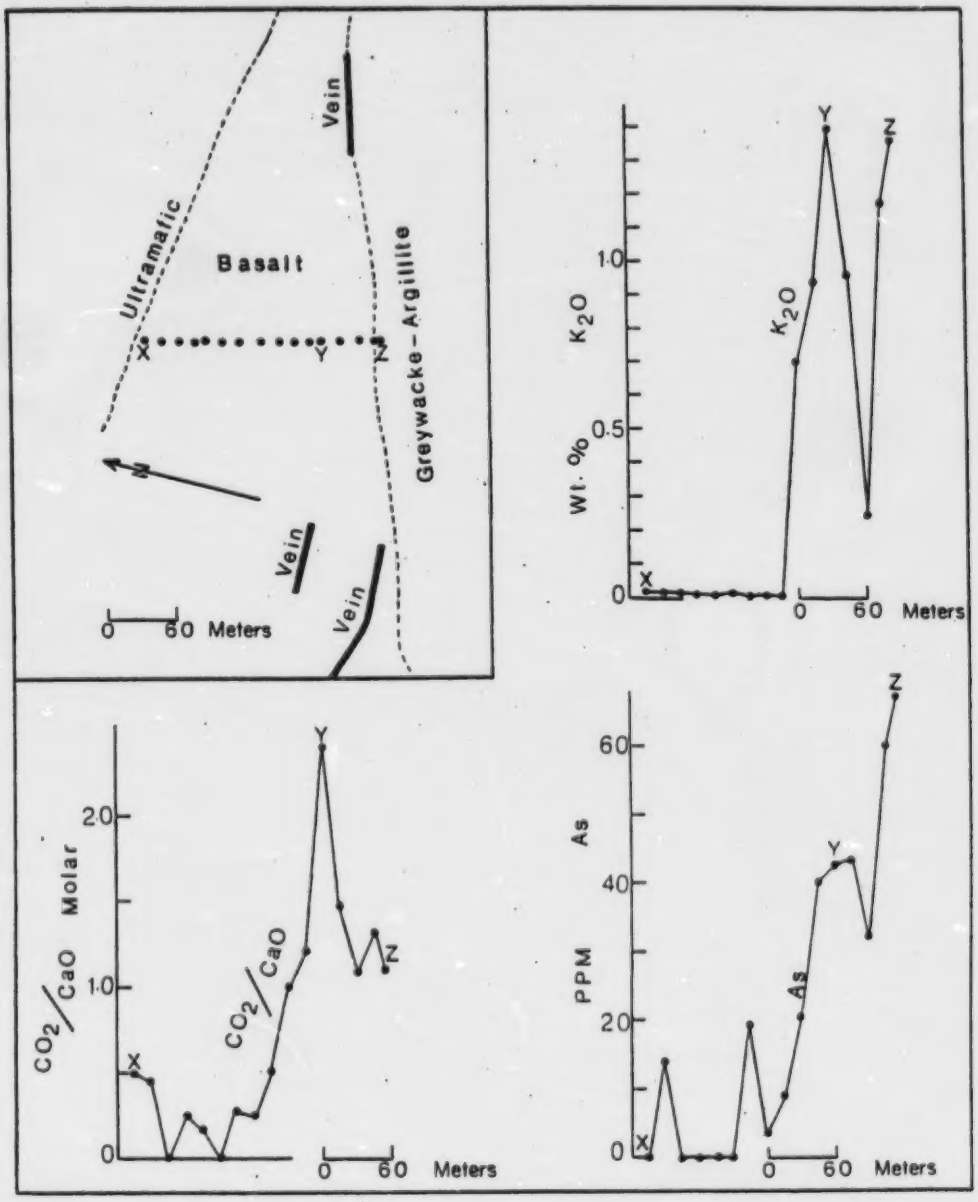

Figure 18. Sample sites (upper left) and plots of CO_2/CaO, K_2O and As, relative to veins on part of the 1400-foot level, Pamour #1 Mine.

Acknowledgements

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APPENDIX A

Analytical Data for Certain Major and Trace Components

(For sample locations, see accompanying maps.)

ULTRAMAFIC ROCKS
TISDALE, WHITNEY, DELORO

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
WT 9	0.05	016.	8.16	0.35	4	—				
10	0.07	0.23	7.12	0.42	4	—				
12	0.01	0.16	4.99	0.18	1	—				
14	0.02	0.09	6.49	4.90	2	—				
17	0.03	0.07	5.29	0.28	3	—				
40	0.001	0.05	7.25	26.90	ND	—				
42	0.002	0.11	6.84	21.60	ND	—				
45	0.03	1.00	8.32	0.16	ND	—				
WT46	0.01	3.77	9.57	0.38	ND	—				
CT 32	0.01	0.34	—	1.49	ND	—				
DT 23	0.001	0.27	2.79	2.10	2	450				
34	0.01	0.14	7.54	0.58	3	400				
35	0.01	0.27	7.82	ND	2	340				
95	0.01	0.24	5.66	ND	ND	280				
193	0.01	0.10	5.50	28.07	ND	27,000				
208	0.01	0.20	9.43	4.74	2	6000				
DT215	0.11	0 47	4.19	0.15	3	11,500				

NORTHERN MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
WT 3	0.45	5.13	4.89	NO	10	—				
4	0.08	1.72	9.49	NO	1	—				
6	0.14	1.23	9.19	0.65	3	—				
7	0.04	2.71	7.19	NO	NO	—				
41	0.16	3.62	4.19	2.87	6	—				
47	0.08	3.77	6.51	0.38	1	100				
48	0.03	1.55	6.23	2.43	NO	100				
49	0.46	1.77	5.94	3.59	10	150				
50	1.30	0.87	7.08	5.22	30	100				
51	0.07	3.38	9.84	1.92	NO	1800				
52	0.01	2.48	8.42	0.13	NO	100				
53	0.01	1.91	8.09	0.26	NO	100				
74	0.05	2.43	4.47	2.55	5	—				
75	0.16	1.75	8.81	1.11	3	—				
WT 76	0.21	1.99	6.54	NO	4	—				
RT 29	0.06	3.46	—	NO	26	—				
32	1.42	3.24	—	10.80	25	—				
33	0.07	3.50	—	6.50	2	—				
RT 34	1.77	2.02	—	5.80	31	—				

NORTHERN MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
RT 35	0.61	2.16	–	5.00	10	–				
36	0.02	1.51	–	ND	1	–				
RT 37	0.12	0.23	–	31.2	3	–				
CT 25	0.24	2.08	8.10	0.20	2	300				
26	0.13	2.29	6.15	ND	3	240				
31	0.05	1.62	–	0.35	1	–				
33	0.13	2.22	–	ND	4	200				
34	0.03	1.75	–	ND	2	175				
35	0.01	1.96	–	ND	1	250				
CT 59	1.20	2.56	2.80	2.83	34	2500				
DT 19	0.03	2.36	8.10	0.88	1	1500				
20	0.04	1.62	9.08	0.73	1	225				
21	0.03	3.44	6.71	0.73	1	225				
22	0.03	1.35	7.68	ND	ND	80				
23	0.001	0.27	2.79	2.10	2	450				
24	0.02	1.96	8.24	0.12	ND	300				
25	0.18	2.49	3.38	ND	5	450				
DT 26	0.04	2.48	7.82	ND	1	370				

NORTHERN MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT27	0.06	1.55	6.98	ND	1	310				
28	0.06	0.81	9.22	ND	3	210				
29	0.06	0.81	9.22	ND	3	250				
30	0.05	2.29	9.22	0.64	1	60				
31	0.10	1.21	9.22	0.06	4	62				
32	0.03	3.03	3.63	ND	ND	50				
33	0.02	1.48	7.82	ND	ND	650				
36	0.07	1.35	8.54	ND	3	400				
74	0.04	2.16	7.82	ND	1	125				
75	0.06	2.55	8.72	ND	1	300				
89	0.01	0.20	—	27.8	ND	—				
90	0.03	2.09	10.90	6.00	2	2,800				
91	0.03	6.63	4.89	4.16	ND	20,000				
93	0.02	3.18	4.68	0.65	ND	160				
94	0.02	3.49	7.40	2.64	ND	1800				
96	0.55	2.63	5.52	7.88	11	55,000				
103	0.05	1.65	16.09	6.86	ND	2600				
156	0.84	2.13	7.40	11.96	21	27,500				
158	0.48	0.96	7.82	6.83	16	1050				
DT192	0.12	1.05	2.51	0.92	3	2240				

NORTHERN MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT194	2.25	0.44	6.43	8.43	64	—				
196	0.02	1.91	6.43	3.71	ND	12,000				
204	0.02	0.17	10.67	10.99	ND	520				
205	0.02	2.09	3.28	0.51	ND	1000				
209	0.06	0.15	8.66	2.61	3	240				
211	0.01	0.20	5.59	28.31	ND	350				
212	1.35	1.62	3.28	4.92	24	570				
214	0.36	1.28	3.70	3.42	11	5000				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
WT55	0.03	2.97	6.13	4.06	ND	100				
56	0.05	1.23	8.31	ND	1	100				
57	0.10	2.67	6.79	5.04	1	2350				
58	0.81	1.53	9.45	6.81	23	100				
59	0.02	2.62	10.19	6.61	ND	150				
61	0.31	3.24	7.55	ND	4	—				
62	0.13	4.35	6.12	0.11	1	—				
65	0.04	0.81	12.80	1.70	ND	350				
69	0.16	1.78	8.33	12.45	3	—				
70	0.01	2.76	8.43	7.38	ND	—				
71	0.06	1.95	6.82	2.36	ND	—				
72	0.04	2.35	6.65	0.61	ND	—				
WT73	0.03	1.59	12.72	2.74	ND	—				
RG 136	0.11	2.70	6.02	—	ND					
139	0.09	1.86	10.56	0.10	2					
140	0.06	1.62	14.97	9.00	ND					
256	0.63	0.78	11.01	9.90	14					
257	1.02	2.05	5.47	3.20	9					
RG 260	0.02	1.15	12.55	10.70	ND					

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
RG 267	0.13	3.05	8.09	7.09	6	—				
RG 268	0.08	2.52	8.32	1.60	2	—				
RT 1	0.17	2.36	6.78	7.20	5	4000				
2	0.04	3.24	—	6.40	1					
3	0.02	2.43	5.45	4.00	ND	13,200				
4	0.04	1.75	—	0.10	ND					
5	0.03	2.22	6.15	ND	ND	1420				
6	0.13	3.26	—	2.50	3					
7	0.09	1.95	11.66	3.40	2	4100				
21	0.01	0.24	9.79	10.10	ND	1740				
22	0.03	5.81	5.88	ND	ND	800				
27	0.05	1.32	—	4.50	ND	—				
30	0.05	3.29	—	ND	1	—				
31	0.06	3.24	—	0.30	1	—				
RT 38	0.04	1.68	—	1.40	1	—				
RW 8	—	—	7.68	ND	—	850				
10	—	—	9.36	ND	—	750				
RW 12	—	—	10.76	0.03	—	2500				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
RW 14	—	—	11.66	7.64	2	5000				
RW 16	—	—	10.90	1.25	6	500				
CT 1	0.07	3.23	8.45	ND	2	190				
2	0.15	2.29	8.80	ND	5	940				
5	0.05	2.22	7.30	1.14	2	380				
6	0.17	3.78	6.70	5.08	4	6900				
7	1.26	0.34	4.75	3.83	41	7550				
8	1.08	1.62	6.98	12.79	33	28,000				
9	0.02	1.89	5.65	7.32	ND	6800				
10	0.84	1.96	8.59	ND	10	280				
11	0.01	4.21	6.36	5.28	ND	740				
12	0.04	2.70	10.48	2.79	ND	1140				
13	0.02	6.14	2.24	ND	ND	1000				
14	0.01	2.56	8.24	ND	1	3000				
15	0.02	1.55	13.13	9.83	ND	5650				
16	0.03	1.51	10.55	0.33	2	270				
17	0.42	1.62	10.34	ND	16	1200				
18	0.03	2.29	11.66	10.48	ND	710				
CT 19	2.40	0.70	5.66	ND	29	250				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
CT 20	0.02	2.42	7.33	ND	ND	300				
21	0.05	2.79	8.24	ND	2	280				
22	0.03	2.29	9.71	ND	2	210				
23	0.03	1.62	7.75	ND	1	450				
24	0.03	2.70	11.18	1.59	ND	550				
27	0.30	3.57	4.89	ND	9	300				
28	0.14	4.04	—	ND	3	65				
29	0.07	2.96	—	2.79	ND	50				
30	0.06	1.34	—	0.20	1	325				
47	1.20	2.90	7.90	3.04	26	360				
48	0.04	4.38	7.35	4.00	ND	750				
49	0.06	2.90	6.20	5.10	ND	350				
50	0.04	3.03	—	ND	ND	—				
51	0.12	2.29	8.95	ND	2	1650				
61	0.01	1.35	10.21	4.56	ND	140				
62	0.01	1.55	10.80	6.63	ND	1500				
67	1.29	1.72	7.20	11.79	38	1230				
68	0.33	1.29	6.08	5.69	14	—				
69	0.25	1.92	9.85	8.00	8	—				
CT 70	0.18	2.32	7.75	7.09	6	—				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
CT 71	0.99	1.66	7.19	6.55	26	325				
CT 75	0.41	2.46	8.17	6.87	12	—				
DT 11	0.05	2.43	12.20	4.52	ND	380				
12	0.18	3.57	7.40	ND	4	190				
13	0.29	3.10	7.40	0.06	5	125				
14	0.02	1.08	11.70	4.08	1	4750				
15	1.56	2.70	7.48	0.75	29	8400				
16	1.62	2.02	6.43	ND	27	870				
17	0.12	2.02	9.71	0.44	3	250				
18	0.01	2.90	8.24	6.35	ND	7250				
37	0.78	0.94	5.59 ~~5.60~~	5.66	20	6050				
38	0.12	2.43	8.66	10.35	4	430				
39	0.09	0.74	6.98	7.04	2	390				
40	1.08	0.40	11.70	14.07	22	3100				
70	0.31	2.60	8.24	ND	7	225				
72	0.31	4.00	5.73	2.17	5	1180				
77	0.25	3.08	5.73	0.65	7	810				
78	0.36	2.26	10.10	ND	14	1200				
DT 79	0.06	3.21	6.43	0.20	ND	1100				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY, AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT 80	0.04	3.48	8.50	0.78	1	6750				
81	—	—	10.80	7.31	1	340				
84	0.31	2.28	9.50	8.57	8	2000				
85	0.01	1.62	7.82	4.92	1	11,500				
86	0.25	1.89	8.94	10.16	6	7450				
87	0.29	2.21	6.84	6.42	8	950				
98	0.29	3.44	8.03	ND	3	370				
100	—	—	—	2.42	2	390				
101	0.12	4.34	8.17	ND	3	1650				
102	0.05	1.67	11.75	1.50	1	14,500				
104	0.03	2.21	7.00	2.28	1	6000				
105	1.18	0.88	7.84	7.18	32	150				
106	0.04	4.14	8.26	5.94	1	180				
107	0.01	4.22	3.92	8.00	ND	240				
108	0.05	2.27	7.98	0.39	1	1450				
109	0.01	1.35	9.09	7.96	1	230				
110	0.70	1.42	12.52	11.82	19	650				
111	0.02	1.15	12.03	6.72	7	460				
112	0.11	4.78	6.30	ND	1	1750				
DT 114	0.04	1.62	8.12	5.80	1	390				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT 115	0.25	3.00	13.99	11.59	12	12,150				
116	0.01	1.55	9.37	9.09	1	1900				
117	0.02	3.57	8.40	9.45	1	310				
118	0.03	1.82	7.41	6.46	1	1080				
119	0.36	1.69	9.09	9.62	18	11,000				
120	0.24	0.81	8.26	7.91	12	2900				
121	0.60	3.10	4.34	3.43	34	3000				
122	0.60	1.61	7.70	7.23	30	1200				
123	0.01	1.35	6.50	4.55	1	12,500				
124	0.18	0.98	8.00	11.19	3	2830				
125	0.24	0.27	4.30	6.19	1	1650				
126	0.17	1.35	10.20	15.74	8	9500				
127	0.41	2.22	6.70	9.70	21	4000				
128	0.23	1.01	7.10	9.70	9	875				
129	0.36	1.08	6.80	9.17	16	1790				
130	0.02	1.55	4.50	6.04	1	350				
131	0.12	2.36	4.30	6.71	4	1600				
132	2.16	0.36	7.10	18.57	52	54,000				
133	0.72	1.83	5.70	7.38	22	900				
DT 134	0.48	2.76	3.40	4.10	21	4000				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP's

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT 135	0.10	1.40	5.70	7.01	3	3900				
141	0.59	3.42	6.50	2.29	7	450				
142	0.48	1.50	8.50	7.51	16	3200				
143	0.02	2.95	9.40	8.73	ND	120				
144	0.81	1.47	6.92	6.80	20	100				
145	0.06	3.52	6.99	2.65	ND	12,500				
146	1.02	0.58	4.61	4.87	25	40,000				
147	0.28	1.28	8.38	9.88	9	3250				
148	1.68	2.70	9.14	11.52	3	3000				
150	0.16	2.18	9.88	11.21	1.0	1700				
151	0.48	0.96	13.01	12.99	10	9000				
152	0.02	1.62	7.96	3.74	1	3500				
153	0.30	3.40	12.57	12.06	7	9000				
154	0.28	2.60	5.24	4.16	9	1980				
155	0.39	3.77	5.59	3.84	3	430				
157	0.30	2.49	7.03	6.19	10	550				
160	0.01	1.71	8.10	4.88	1	1000				
164	0.03	2.70	7.75	5.85	ND	1000				
169	0.24	0.96	11.87	10.06	8	450				
DT 170	1.02	0.23	10.13	2.80	5	650				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT 171	1.02	1.09	9.95	8.84	24	1800				
172	0.01	2.24	9.33	8.03	1	180				
175	0.48	2.44	9.01	13.83	21	35,000				
176	0.96	2.09	4.63	5.91	31	900				
181	0.25	1.87	—	ND	5	190				
184	0.02	1.40	12.40	2.65	8	1380				
187	0.12	5.08	7.05	10.09	2	64000				
188	0.04	0.66	9.08	8.13	ND	1080				
189	0.30	5.43	7.54	11.76	8	480				
190	0.12	3.87	9.22	9.48	3	1000				
191	0.04	2.36	8.24	ND	ND	710				
195	0.02	3.46	6.43	0.63	1	1150				
197	0.36	1.91	6.43	5.81	10	10,000				
198	0.04	1.96	8.73	ND	ND	19.000				
199	0.12	2.97	7.40	ND	2	1350				
200	0.01	2.47	8.10	7.28	ND	450				
201	0.01	1.70	7.54	3.85	1	16.000				
202	0.42	1.61	7.96	ND	16	700				
203	0.01	2.56	9.15	7.26	ND	580				
DT206	0.05	3.17	7.33	0.48	1	70				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT 207	1.65	2.09	—	3.77	ND	—				
210	0.06	4.25	7.33	ND	ND	1410				
213	0.24	2.16	4.96	4.82	4	510				
225	0.48	1.55	9.23	9.21	13	1560				
226	0.07	2.05	7.40	ND	4	11,500				
227	0.26	1.51	7.61	ND	5	3000				
228	0.08	1.91	6.77	2.06	5	10,000				
229	0.24	3.18	7.26	6.04	5	8000				
231	0.34	0.65	6.98	1.86	5	600				
232	2.23	1.07	7.40	13.80	6.7	1220				
233	0.05	2.80	7.26	ND	1	—				
234	0.28	3.94	5.45	1.23	7	750				
235	0.28	2.59	3.56	1.54	3	1210				
236	0.45	3.29	5.38	8.85	14	33,000				
237	0.30	2.05	6.36	6.53	4	50,000				
241	0.12	1.95	7.86	1.27	3	—				
242	0.22	3.63	7.54	3.18	50	50,000				
243	0.24	4.02	6.57	1.41	5	300				
244	0.07	0.12	4.47	0.28	39	7500				
DT 245	0.03	1.78	10.90	ND	1	2680				

CENTRAL MAFIC ROCKS

TISDALE, WHITNEY AND DELORI TWP's

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb
DT 246	0.02	1.09	11.70	6.65	ND	5300
247	0.38	4.79	6.43	0.04	7	1500
248	0.08	3.59	6.99	ND	2	300
249	0.05	2.24	6.71	1.40	1	250
DT 257	0.24	1.30	8.38	6.05	—	710
RT 92	0.23	1.05	7.82	11.38	5	2000
93	1.08	0.35	10.10	10.17	30	17,500
94	0.23	0.08	10.30	28.50	8	250,000
RT 95	0.34	1.05	6.70	7.89	12	250

VIPOND MAFIC ROCKS (VARIOLITIC)

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
RG244	0.02	2.33	3.78	1.80	ND	500				
247	0.31	0.80	4.76	5.90	8	15,500				
249	0.23	2.55	5.27	7.70	10	3100				
252	0.02	3.20	4.75	3.10	ND	680				
RG261	0.30	3.22	6.98	6.40	8	—				
RT 9	0.03	1.08	7.96	1.50	ND	150				
91	0.21	0.14	13.80	2.40	18	10,000				
RT 97	0.02	0.82	3.07	0.32	5	30				
CT 45	0.04	2.08	8.10	7.93	ND	1100				
73	0.02	3.56	4.05	2.14	ND	2850				
102	0.55	2.25	8.45	ND	10	—				
105	0.58	3.34	6.15	ND	8	—				
114	0.70	2.97	5.87	4.46	21	850				
CT 116	—	—	—	—	6	-				
DT 6	0.04	2.70	4.75	3.26	2	160				
8	0.29	0.94	3.05	0.38	22	125				
DT 44	0.96	1.89	4.47	3.07	30	4750				

VIPOND MAFIC ROCKS (VARIOLITIC)

TISDALE, WHITNEY AND DELORI TWPS

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb
DT 54	0.01	0.89	8.10	5.86	ND	500
55	0.03	3.88	2.28	0.63	1	1550
59	0.02	2.72	3.30	1.31	ND	125
161	0.04	2.99	8.73	7.37	2	1430
165	0.18	3.06	6.64	4.32	6	15,500
168	0.09	4.06	2.27	1.07	4	1350
173	0.01	1.35	8.38	2.39	1	300
180	0.11	1.66	1.66	ND	4	62
186	—	2.39	8.38	0.31	ND	340
DT 224	0.11	3.23	9.71	9.66	1	600
238	0.75	1.35	7.26	7.58	19	30,000
252	0.01	0.09	—	2.48	1	—
255	0.01	2.80	4.75	2.71	1	1410
DT 256	0.02	3.64	7.26	610	1	425

VIPOND MAFIC ROCKS (NON VARIOLITIC)

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
WT 64	0.35	1.59	7.10	4.64	6	1050				
WT 68	0.22	2.48	5.36	7.50	6	687				
RG-108	0.26	2.70	6.02	9.40	3	75				
112	0.08	2.43	8.45	ND	ND	—				
220	0.02	4.25	3.94	1.30	ND	1350				
229	1.78	1.44	8.87	18.20	43	—				
RG 263	0.03	2.85	4.00	2.50	ND	900				
RT 8	0.28	2.80	—	ND	3	—				
10	0.14	4.26	—	7.40	2	—				
11	0.23	2.34	4.75	3.70	4	200				
16	0.64	2.29	—	8.00	22	100				
17	0.03	2.28	—	4.10	ND	600				
18	1.83	0.80	—	3.00	55	150				
19	0.04	4.54	—	2.50	1	360				
20	0.72	3.68	—	4.30	19	1800				
RT 26	0.11	1.76	7.84	10.00	4	4000				

VIPOND MAFIC ROCKS (NON VARIOLITIC)

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
CT43	0.09	2.42	6.00	7.87	1	4000				
44	0.36	0.47	1.81	ND	10	3400				
46	0.01	2.08	6.20	3.14	ND	500				
63	0.60	3.00	7.20	8.64	25	130				
64	0.03	2.70	6.20	5.11	1	350				
65	0.22	2.86	2.37	1.20	6	2850				
72	0.02	3.20	4.96	2.68	ND	320				
74	0.13	4.04	7.75	7.30	5	—				
98	0.28	0.58	8.87	9.57	5	100				
101	0.23	2.29	9.15	0.22	5	500				
103	0.05	2.97	5.80	2.72	2	100				
104	0.04	2.06	5.45	5.56	1	—				
106	0.72	2.41	5.45	ND	9	—				
112	0.19	3.68	6.57	5.49	6	200				
113	0.36	2.16	7.13	7.18	13	250				
CT115	0.24	2.63	5.10	8.51	6	100				
DT 7	0.36	3.57	5.58	4.08	4	120				
9	0.11	3.44	2.58	3.07	1	115				
DT 10	0.72	3.24	6.15	ND	11	2010				

VIPOND MAFIC ROCKS (NON VARIOLITIC)

TISDALE, WHITNEY AND DELORO TWPS

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT 64	0.18	2.80	4.74	0.65	4	140				
71	0.14	2.20	5.73	ND	5	300				
83	0.04	5.11	5.94	ND	ND	10,000				
138	0.16	1.78	6.40	9.85	3	1650				
139	0.07	2.56	6.92	6.64	28	8000				
140	0.05	2.45	4.61	2.31	1	300				
149	0.96	2.93	3.88	5.15	29	4000				
223	0.12	2.59	6.29	10.32	4	300				
239	1.47	0.08	6.50	8.62	46	32,000				
240	0.25	3.20	2.58	1.14	9	830				
250	0.08	0.24	8.52	12.01	6	2380				
251	0.06	0.67	6.71	7.36	2	3150				
253	0.58	0.88	6.15	8.44	20	1700				
DT 254	0.72	0.96	3.91	6.86	23	11,100				

VIPOND MAFIC ROCKS (99 FLOW)

TISDALE, WHITNEY AND DELORO TWP'S

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
RT 96	2.51	3.72	4.61	7.60	58	15,000				
RG 230	0.78	2.30	7.23	16.90	18	—				
232	0.25	2.24		12.80	7	6800				
RG 262	0.10	5.65	4.15	2.50	3	1350				
DT 162	0.12	1.23	4.61	7.07	4	35,000				
163	0.02	3.48	4.76	7.07	3	1450				
166	1.38	1.08	6.66	10.32	49	850				
167	0.36	3.09	8.10	7.07	1.1	1100				
174	2.28	0.61	4.54	6.00	56	76,000				
DT 178	0.36	0.67	5.59	9.57	10	37,000				

GOLD CENTRE MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWPS

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
RG 105	0.22	4.72	5.17	3.80	8	—				
106	0.49	3.37	5.36	3.10	11	—				
225	0.75	3.10	9.03	8.40	1	175				
235	0.10	0.35	—	5.40	2	—				
264	0.08	3.26	6.32	0.80	ND	900				
265	0.77	2.35	9.86	8.70	17	300				
RG266	1.32	2.53	8.85	10.60	28	7500				
RT 14	0.81	2.62	—	6.50	17	—				
RT 23	0.48	1.94	8.12	7.70	18	950				
CT 36	0.06	2.63	—	2.09	1	1800				
37	0.02	2.70	—	4.98	2	975				
38	0.66	2.42	—	10.00	16	300				
39	0.30	2.36	—	9.95	9	2550				
40	0.42	3.23	—	8.81	8					
42	0.42	3.23	6.60	9.41	13	1100				
52	0.36	2.76	8.90	8.34	10	650				
53	0.01	2.29	6.80	5.88	10	350				
CT 54	0.01	4.38	8.30	5.33	8	1200				

GOLD CENTRE MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWPS

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
CT 55	0.60	3.03	4.80	4.56	18	2830				
56	0.02	3.57	6.80	4.32	ND	250				
57	0.04	1.62	7.30	5.27	1	500				
58	0.40	1.82	6.50	5.61	20	860				
60	1.57	2.49	2.40	3.69	34	850				
66	0.17	3.17	8.92	0.11	5	380				
95	0.79	1.50	—	1.70	27	—				
96	0.40	2.29	—	1.69	17	175				
97	0.06	2.97	8.59		3	—				
107	0.19	2.36	8.94	3.43	7	—				
CT 109	0.12	2.49	—	2.10	2	—				
DT 1	0.71	1.75	10.03	0.31	24	450				
2	3.14	1.62	6.64	1.13	41	456				
3	0.72	1.89	8.91	0.13	12	1050				
4	0.25	2.70	8.55	1.00	6	1500				
5	0.12	3.30	8.94	1.19	2	1350				
45	0.36	3.52	9.78	9.79	9	1780				
46	1.55	2.36	2.24	1.70	35	6950				
DT 47	1.38	2.12	4.47	3.64	32	2150				

GOLD CENTRE. MAFIC ROCKS

TISDALE, WHITNEY AND DELORO TWPS

Sample No.	K_2O wt %	Na_2O wt %	CaO wt %	CO_2 wt %	Rb ppm	As ppb				
DT48	1.61	2.41	4.75	3.17	48	850				
49	0.48	2.80	5.87	5.23	13	875				
50	1.06	4.20	5.59	8.80	24	80.000				
51	0.94	2.53	3.63	4.60	26	1500				
52	0.24	1.86	6.43	5.07	9	1500				
56	0.18	2.83	7.33	6.02	7	2300				
57	0.97	1.44	6.43	5.39	25	900				
63	1.06	1.70	6.99	5.31	31	180				
65	0.49	2.80	8.66	6.37	15	6000				
66	1.53	2.79	3.13	2.20	42	24000				
67	0.07	3.50	7.82	3.51	2	610				
220	0.02	3.44	6.08	5.43	ND	1770				
DT240	0.25	3.20	2.58	1.14	9	830				